ASSESSMENT OF THE 1995 & 1996 FLOODS AND LANDSLIDES ON THE CLEARWATER N.F.

PART 1: LANDSLIDE ASSESSMENT

ASSESSMENT OF THE 1995 & 1996 FLOODS AND LANDSLIDES ON THE CLEARWATER NATIONAL FOREST

PART I: LANDSLIDE ASSESSMENT

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EXECUTIVE SUMMARY

The Clearwater National Forest landslide assessment of the November-December '95 and February '96 storm events was initiated by the Regional Forester in a letter dated April 4, 1996. The broad objectives of the study were to engage in a dialog with the public on the causes and effects of landslides to the Northern Rockies ecosystem and to seek technical information that could improve our understanding of the landslide process.

A public meeting was held in Orofino, Idaho, on May 16, 1996, to solicit comments, questions, and concerns from the public. From the public meeting and the questions and objectives in the Regional Forester's letter, the authors developed the following eight objectives (a complete list of internal Forest Service questions and public questions is presented in Appendix A):

1. Describe the storm and flood conditions that triggered the landslide events,
2. Compare the relative landslide rates by land use and landscape characteristics,
3. Compare results of this study to the results from the 1974-76 study period on the Clearwater NF,
4. Compare the 1995-96 landslides to the long term background landslide sediment rate,
5. Evaluate the effectiveness of current road construction standards in reducing landslides,
6. Evaluate the effectiveness of road obliteration in reducing landslides and suggest prioritization criteria for road obliteration.
7. Provide options to reduce landslides on the Clearwater NF,
8. Describe the impacts of floods and landslides on streams,

A preliminary draft of this report was reviewed by twelve individuals in academia, the U.S. Forest Service, U.S. Geological Survey, state agencies, and private industry with backgrounds in slope stability, watershed and forest management. A presentation of the preliminary report was held at the University of Idaho on November 1, 1997 attended by approximately 100 individuals. Some comments received have been incorporated in this final report.

Objectives 1 through 7 are addressed in Part I: Landslide Assessment. Objective 8 is addressed in Part II: Stream Response.

Objective 1 - Storm and flood conditions: The landslide events of the winter of 1995-96 fall into three distinct episodes. The first was November and December 1995, followed by February 1996. The last episode was during the spring melt of 1996. During October through November of 1995, precipitation in the Clearwater River drainage was nearly 200 percent of normal. November 23 was the first of 13 consecutive days of precipitation. The resulting streamflows were between 2 and 25-year events. The events leading to the February landslides were similar to those during November, i.e., warm temperatures and several days of rainfall on a deep, widespread snowpack. The resulting streamflows were between 2 and 100-year events. Field personnel indicated that significant landsliding occurred during the spring

snowmelt season. This landsliding episode was set up by the wet antecedent conditions of the fall and winter. Peak streamflows were not unusual.

Objective 2 - Relative landslide rates: The number of landslides on the Clearwater NF with volume greater than 25 cubic yards was 907. Over half (58%) of the landslides were associated with roads. A road associated landslide was defined as originating between the top of the cutslope to 100 feet below the base of the fill. The second highest land use was natural (no management) with 29% of the slides. The remaining 12% of the landslides were in harvest units. Landslides associated with fire totaled two and comprised less than 1% of the 907 landslides. There were six landslides (1%) that were not classified as to land use. Most landslides were between 26 and 100 cubic yards regardless of land use. The authors' best estimate of the total volume displaced was 700,000 cubic yards with a range of 400,000 to 900,000 cubic yards. Thirty-six percent of the landslide volume was associated with roads, 5% with harvest, and 59% with natural. The best estimate of the volume that delivered to streams is 400,000 cubic yards with a range of 300,000 to 700,000 cubic yards. The delivered volume from roads was 25%. Harvest landuse comprised 4% of the delivered volume. The remaining 71% was from natural landuse. Border and Batholith were the two parent materials with 84 percent of the landslides, regardless of the landuse. Ninety-four percent of all landslides occurred below 5000 feet elevation. South, southwest, and west slopes were more likely to experience landslides. This was true in all land use categories. The steepest slopes experienced the most landslides. The two highest landslide rates were on Breaklands and Mass Wasting landforms.

Objective 3 - Historical comparison: This was only available for the 1974-76 period. The results were quite similar with respect to triggering weather events and landslide results.

Objective 4 - Comparison to background rate: Sediment delivery to watersheds with landslides was extremely variable across the Forest ranging from 0.04 to 270 times the background rate.

Objective 5 - Road construction standards: While there were indications that the mix of roads on the Clearwater NF were less landslide prone, a strong scientific conclusion could not be reach by the authors, because of the difficulty in identifying road age and construction practices. The authors suggest a more detailed study is needed.

Objective 6 - Road obliteration: The authors reviewed in the field six miles of obliterated roads. The authors would have expected up to 10 landslides from these roads. The authors were not aware of any road associated landslides occurring on the treated roads.

Objective 7 - Options to reduce landslides: The Forest Land System Inventory and the five landslide indicators should be used to identify high hazard areas.

INTRODUCTION

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The following team was assembled for the landslide assessment:

Soils	W. Dale Wilson, Consulting Soil Scientist, USFS Retired
Geomorphology	Robert L. Schuster, Ph.D., Scientist Emeritus, USGS
Hydrology	Terrance W. Cundy, Ph.D., Potlatch Corp. Hydrologist
Aquatics	C. Michael Falter, Ph.D., University of Idaho Aquatic Ecology Professor
Engineering & Analysis	Randy B. Foltz, Ph.D., USFS Research Scientist
Roads Engineering	James A. Saurbier, USFS Transportation Engineer
Slope Stability	Douglas E. McClelland, USFS Geotech Engineer

The team acknowledges the contribution of Ron Heinemann who supervised the field and data collection and, therefore, was included as an author of Part I.

A public meeting was held in Orofino, Idaho, on May 16, 1996, to solicit comments, questions, and concerns from the public. From the public meeting and the questions and objectives in the Regional Forester's letter, the authors developed the following eight objectives (a list of internal Forest Service questions and public questions are included as Appendix A):

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LANDSLIDE BACKGROUND

Types and Processes

As originally defined by Varnes (1958), the term "landslide" denoted gravitational downward and outward movement of slope-forming materials composed of rock, soil, artificial fills, or combinations of these materials. The moving mass was seen to proceed by one or more of three principal types of movement: falling, sliding, or flowing. The word "landslide" is widely used, and, no doubt, will continue to be used, in the United States and worldwide as an all-inclusive term for almost all varieties of slope movements, including some that involve little or no true sliding, such as debris avalanches, and debris, earth, and mud flows.

Landslides can be classified in many ways, each having some usefulness in emphasizing processes and characteristics pertinent to recognition, avoidance, control, remediation, or other purposes. Among the attributes that have been used as criteria for identification and classification are: type of movement; kind of geologic material; rate of failure; geometry of the failure surface, the failed mass, and the resulting deposit; causes of failure; relation or lack of relation of slide geometry to geologic structure; degree of development; age; and state of activity (Varnes, 1978). However, in order to obtain a fairly simple classification that could be used by scientists, engineers, planners, and the public throughout the United States and worldwide, Varnes (1978) based classification on the two chief criteria: 1) type of movement and 2) type of geologic material. As a result, landslides have been subdivided into five major groups: falls, topples, slides (including slumps), spreads, flows (including avalanches), and combinations of two or more of these.

Nearly all of the landslides described in this study were varieties of slides, slumps, avalanches, flows, or combinations of these. The slides and slumps in soil and rock have moved along discrete failure surfaces or series of surfaces. Soil and debris avalanches have occurred as badly broken up ("jumbled") masses on steep slopes; they do not have discrete failure surfaces. Debris flows and mud flows are mixtures of water and soil that move as "flowing" masses, primarily as debris flows or mud flows. Many of the 1995-96 Clearwater NF landslides were combinations of these types of slope failures. In a common scenario, failure began on a steep slope as a thin slide or slump in surficial soil and fragments of weak rock, which then was transformed into a debris avalanche, debris flow, or mud flow. In some instances, highly saturated masses of soil and rock led to debris flows with runout distances of as much as several tens of yards.

Immediate Causes of Slope Failure

Landslides can have several long-term causes, including varieties of geologic (e.g., weak geologic materials), morphologic (e.g., steep slopes), hydrologic (long-term ground-water effects), and human (e.g., mining, construction of road cuts and fills) antecedents, but commonly only one or two immediate causes of failure (i.e., "triggers" or "triggering events"). By definition, a landslide triggering event is an external stimulus such as intense rainfall, snowmelt, earthquake shaking, volcanic eruption, stream erosion, storm waves, or the activity of man (e.g., excavation or physical loading of a slope) that causes a near-immediate response in the form of a landslide by rapidly increasing the stresses in the slope or by reducing the strength of the slope materials (Wieczorek, 1996). The requisite short-term frame of cause and effect is the critical element in the identification of a landslide trigger.

The immediate causes of the 1995-96 landslides in the Clearwater NF were 1) heavy rainfall from winter storms that moved across northern Idaho from the Pacific Ocean, and 2) resulting melting of parts of the existing snow pack due to this heavy rain. Thus, the slope-movement events were triggered by water from rain and snowmelt, which combined to quickly lower the shear strengths of the materials that made up existing steep slopes in the mountainous terrain.

STUDY AREA

The Clearwater National Forest is located in Clearwater, Benewah, Shoshone, Idaho, Lewis, and Latah counties in north central Idaho (see Figure 1). It lies west of the Montana border and is bounded on three sides by four other National Forests; the Lolo in Montana; the Bitterroot in Montana add Idaho; the Nez Perce in Idaho; and the St. Joe in Idaho. The forest boundary encompasses all or major portions of the drainages of the North and Middle Forks of the Clearwater River, the Lochsa River, and the Palouse River which are all part of the Columbia River system. The following discussion is based upon the Clearwater NF Forest Plan (USDA, 1987). If the reader wants more details the authors suggest reviewing the Forest plan.

The Clearwater NF consists of 1,837,116 acres of National Forest System lands, and the boundary encompasses 146,083 acres of private and other public lands. A portion (259,165 acres) of the Selway-Bitterroot Wilderness and a portion (23,606 acres) of the Middle Fork-Lochsa Recreation River cover approximately 15% of the forest.

Streams on the Clearwater National Forest drain steep, precipitous landscapes with elevations on the Forest ranging from the Bitterroot Mountains of greater than 7,200 ft down to the main Clearwater River at 980 ft. The climate is characterized by long, dry, and very warm summers (high temperatures near 95° F) and cool, wet winters. Annual precipitation is approximately 24 inches at lowest elevations and greater than 79 inches in the Bitterroot Mountains.

Watershed systems on the Clearwater NF are part of the lower Snake River system and have a direct effect on water recreation, sport and commercial fisheries, water transportation, irrigation, and downstream hydroelectric dams.

The Forest provides habitat for over 350 species of wildlife including moose, whitetail deer, mule deer, Rocky Mountain goats, mountain lions, black bears, and numerous small mammals and birds. The northern bald eagle and Rocky Mountain gray wolf are listed as endangered on the Forest. Important fishery resources on the Forest include blue-ribbon cutthroat trout streams. Larger drainages include habitats for anadromous steelhead and chinook salmon.

Recreation on the Clearwater NF includes big-game hunting, fishing, camping, cross-country skiing, rafting, hiking, and wilderness trips. Recreational opportunities exist along numerous rivers and streams. The Forest contains part of the Selway-Bitterroot Wilderness as well as four other areas recommended for wilderness.

Range resources on the Clearwater NF are somewhat limited by heavily timbered, steep, remote terrain and by short growing seasons at the higher elevations. Present primary range consists of meadows interspersed in forested lands and by temporary production of forage after timber harvest or fire.

Geologic Setting

For this study the authors recognized five geologic parent materials. These five parent materials were used in subsequent analysis of the landslide hazards. They are described below.

The Idaho <u>Batholith</u> consists primarily of granitics. Granitics are coarse textured igneous intrusive rocks that today are commonly deeply weathered and have resulted in grussic (loose single grain) soils. Exposed surface soils derived from these materials are subject to severe surface and landslide erosion.

<u>Border</u> derived material, now called Western Idaho Suture Zone, are high grade metamorphic rocks of the Belt group dominated by interbedded schists, gneisses, impure quartzites and pegmatites. Weathered layers with high mica content are common. Resulting soils are cohesionless and typically contain 10 to 20% mica, which significantly decreases shear strength.

<u>Belt</u> materials are weakly metamorphosed rocks which typically consist of clean quartzite, argillites, siltites, and carbonates. Soils derived from these materials usually contain large percentages of angular coarse fragments which increase shear strength.

Columbia River <u>basalts</u> are layered volcanic materials which today vary from hard weakly weathered rocks to extensively weathered rocks. Resulting soils are fine textured and

cohesive.

Materials resulting from surface erosion and deposition over geologic time are termed alluvium. Alluvium is found in all recent stream terraces adjacent to major streams and old terraces and bottomlands. These lands have old well developed, silty soils and commonly have high water tables and fragipans. Alluvium soils range from fine textured silts to stream gravels.

Figure 2 is a general geology map of the Clearwater NF. The geologic record begins about 2.5 billion years ago with a sea covering north Idaho. The area included in the Clearwater National Forest was at the mouth of a large bay extending east to somewhere around Helena, Montana. Silt, clay, and fine sand were brought to the bay and deposited as siltstones, shales, and dirty sandstones. These became the lower Belt rocks, the Pritchard, Burke, Revett, St. Regis, and Wallace Formations. The only living things were the most primitive of blue-green algae living in the oceans.

The area was under the sea until about 300 million years ago, just before the age of dinosaurs. Then tectonic rise (from plate collision and volcanic activity centered around the Seven Devils area) caused the area to rise above sea level. During this interval, sediments continued to be deposited on top of the Belt rocks. Very old metamorphism and a number of deformations preserved in the Belt rocks imply that the area was above sea level and subject to erosion at another time in the past, but no direct record survives.

Continuing volcanic activity presaged the intrusion of the Idaho Batholith. This great body of granitic rock rose in late Cretaceous time, about 150 million years ago. Its intrusion pushed everything above it upward, including the overlying Belt rocks. This was a time of much faulting and mountain building and was the time that the Belt rocks were deformed and highly metamorphosed to gniesses and schists. The central part of the Batholith was implaced in the early Tertiary period, about 60 million years ago. This pluton intruded and metamorphosed both the Belt rocks and the older granitics, converting some older granitics into gneiss and grussic granite. Hydrothermal alteration subjected areas of the existing gneisses, schists, and granites to intense chemical attack, altering them to clay minerals. Erosion stripped the overlying rocks down to the lower Belt rocks and exposed the Border Zone and the newly formed Batholith.

Landform Setting

The following are brief descriptions of the major groups of landforms used in this analysis. The groups correspond to landforms used in the Clearwater Land System Inventory and Region 1 Landtype Associations.

Breaklands are oversteepened slopes resulting from uplifting of the land surface and subsequent downcutting of rivers and streams. Hill side steepeness is commonly in excess of 60%;

bedrock is moderately to weakly weathered, with weakly developed colluvial soils. This landform is considered one of the most unstable on the Clearwater NF.

Mountain slopes have formed by fluvial and colluvial processes. The ridges are generally convex and the sideslopes are straight. Hill side steepness generally ranges from 35 to 60%. Bedrock weathering is variable with weakly to moderately developed soils.

Mountain ridge tops are broad convex slopes that commonly occur above mountain slope landforms and adjacent to steep glaciated lands. They have formed mainly by physical weathering and periglacial frost-churning. They are usually undisssected. Hill side steepness is dominantly 5 to 40%. Soils contain large percentages of coarse fragments and are highly permeable. These landforms are thought to be the most stable on the Clearwater NF.

Gentle hills consists primarily of gently to moderately sloping hills with relief less than 300 feet. These landforms are the result of shallow stream dissection of deeply weathered surfaces. Hill side steepness is typically in the range of 20 to 40%. Soils are deep and bedrock is extensively weathered.

Mass wasting landforms contain historic rotational and translational failures. These include a variety of types of failures, such as debris avalanches, slumps and deep seated failures resulting in benchy topography with hill side steepness ranging from 20 to 60%.

Valley landforms include both recent terraces and high terrace remnants, debris fans and colluvial toeslopes. Hill side steepness ranges up to 30% on terraces and fans and up to 60% on toeslopes and eroded faces of terrace remnants. Soils are weakly developed and commonly contain poorly drained areas.

METHODS

Storm and Flood Conditions

To describe the magnitude of storm and flooding events the authors used weather records collected by NOAA and weather stations maintained by the Clearwater NF. Stream flows were obtained from data published by the USGS. The authors also relied on the collective knowledge of individuals familiar with historic landslide and flood events on the Clearwater NF.

Landslide Assessment

Study Design

The study design relied on both a field inventory and aerial photo interpretation. The landslide field inventory was performed by two field crews under the authors' direction and one under

the direction of the Powell Ranger District. Interaction with the Powell RD field crew was limited to common data sheets. This caused the authors concern because of possible differences in interpretation and measurement techniques. However, the Powell data has been included in this report.

Aerial reconnaissance flights by Clearwater NF personnel following the November and February storms determined that large numbers of landslides had occurred in widely dispersed and inaccessible areas. Therefore, it was decided that in order to get complete inventory coverage it would be necessary to supplement a field inventory with an aerial photograph based inventory. The entire forest with the exception of the Palouse district and the Selway Bitterroot Wilderness was flown in July 1996 at a scale of 1:15840 (4 inches = 1 mile) with stereo coverage. The wilderness was not included because of cost; flight lines for the non-wilderness portion were already available. To develop the necessary flight lines the cost for the aerial photos would have increased from $35,000 to about $70,000. The entire photo interpretation phase of the project was completed by Dale Wilson between October 1996 and February 1997.

Personal communications of the authors with researchers studying the 1995-96 flood events in coastal Oregon suggests that significant landslides can occur under full, mature canopies that may not be seen on aerial photos. In the opinion of the authors this was not a major problem in this Clearwater NF study. Generally canopy cover on the Clearwater NF is less than in coastal Oregon. An inspection along 30 miles of road between Canyon Work Center and the Bungalow site showed that field observed, impacted streams could be linked to landslides observable on aerial photos. Pending the final report from the Oregon study, the Clearwater NF may want to conduct its own evaluation of field versus aerial photo census of landslides.

Inventory Procedures

Field Inventory Landslide locations identified from the initial aerial and ground reconnaissance were transferred to 1:24000-base quadrangle maps for use by the field crews to aid in locating the landslides. Sites visited by the field crew were not a random sample. The field sites tended to be in areas of reasonable access and high landslide concentration to visit as many sites as possible. Access to landslide locations was obtained by use of mountain bikes, motorcycles, and hiking.

Field data-acquisition methods used by the landslide crews are summarized as follows:

1. Slide-initiation points were surveyed using hand-held Global Positioning System units.
2. Landslide measurements (width, depth, and length) for computing landslide volumes were obtained using a survey tape and range finder.
3. Geology of the site was recorded based on exposed bedrock and nearby outcrops.
4. Hill side steepness and slope aspects were measured using a clinometer and compass or obtained from topographic maps.

5. Groundwater and surface-water conditions were recorded from on site inspection.
6. Elevation was obtained from topographic maps.
7. Landform was obtained from on site inspection.
8. An onsite estimate was made of the volume and the delivery to the stream or floodplain.

Data on landslides were gathered from June through September 1996. An additional six months were required to complete many of the data fields from information in the Clearwater NF Supervisor's Office and to prepare the landslide database.

Aerial Photo Inventory Data collected in the aerial photo interpretation phase of the inventory followed the same format and used the same definitions described for the field based inventory. Procedures unique to the aerial photo interpretation are summarized below. A detailed description of the aerial photo analysis procedure is included in Appendix B of this report.

Landslides were classified into one of five land use categories of road, partial cut harvest, clearcut harvest, fire or natural. The road category was defined as a landslide originating between the top of a road cut and 100 feet below the base of the fill. A landslide originating in a harvested area was classified into either partial cut harvest or clearcut harvest. Fire was named as the land use only if the area had been burned by a wildfire in the proceeding 10 years. If a landslide origination was not in one of the preceding four categories it was placed in the natural land use category.

Hill side steepness was categorized using 5% intervals. All steepnesses above 56% were categorized as 56%+.

Landtypes for each landslide were obtained from the Clearwater NF's Geological Information System (GIS) maps. These maps were developed from the Clearwater Land System Inventory (1983).

The watershed name was taken from the 1:24000 topographic maps. An unnamed tributary was given the name of the next larger stream named on the map. Landslides in small unnamed tributaries draining directly into large streams, such as the Lochsa River were given the Lochsa River name.

The volume of each slide was placed in five size categories which were

1) less than 25 cubic yards,
2) 26 to 100 cubic yards,
3) 101 to 200 cubic yards,
4) 201 to 1,000 cubic yards, and
5) greater than 1,000 cubic yards.

The volume includes the source area plus any scour as the landslide moved down the hillside

or stream channel.

The fraction of the total sediment volume that reached a floodplain or a stream was divided into four size categories as follows

1) less than 10 %,
2) 11 to 25%,
3) 26 to 50%, and
4) 51 to 100%.

Data Analysis

Storm and Flood Conditions. The authors reviewed precipitation totals, storm totals, and snowmelt depths spatially across the Clearwater NF. Peak stream flows were compared to the historic record and return period determined.

Relative Landslide Hazard. Landslide rates per 1,000 acres by parent material, hill side steepness, aspect, elevation, and landform were determined to evaluate the landslide hazard.

Comparison to Previous Studies. An estimate of the natural background landslide sediment rate and a comparison with the 1974-1976 landslide events was made to provide a basis for comparison to historic landslide events in this ecosystem. The only earlier definitive applicable study for the Clearwater NF was made by Megahan et al. (1978) on the 1974-1976 sequence of storms and landslide events. The studies were compared on the basis of landslide volumes, parent materials, and land use.

Effectiveness of Current Road Construction Standards. The evaluation of the effectiveness of the current road standards in reducing landslides was performed by summarizing the landslide data by decade of road construction. From the beginning the authors recognized that date of road construction was an imperfect surrogate for road construction practices. After struggling with this analysis for over six months, the authors are even more convinced that decade of road construction is an imperfect surrogate for road construction technique.

Effectiveness of Road Obliteration. The evaluation of the effectiveness of road obliteration at reducing landslides was done by means of site visits to obliterated roads. The number of landslides observed were compared to the expected number of landslides from active roads.

Options to Reduce Landslides. To reduce landslides the authors reviewed the landslide database and analysis and developed a consensus set of options.

RESULTS

Storm and Flood Conditions

The Clearwater River drainage experiences periodic floods and periodic landslide events. Major floods occurred in 1919, 1933, 1948, 1964, 1968, and 1974. Most of these are documented in streamflow records.

There is no information available to assess landslides from the 1919 event.

In 1933 the largest flow event ever occurred on the St. Joe River and the third largest on the North Fork Clearwater, the Clearwater, and the Lochsa River. Casual review of 1935 photos suggest there were major landslide events associated with the peak flows of 1933. A study of this landslide episode could be done from analysis of the 1935 photos.

The largest event ever on the Selway and Lochsa Rivers occurred in 1948. Anecdotal reports suggest major landslides were associated with the 1948 floods.

The second largest event on the Lochsa and the third largest event on the Selway occurred in 1964. It may be possible to document these landslides by using aerial photos. There was no report specific to the Clearwater NF.

There were no notable stream flows in 1968.

In 1974 the largest flow event ever occurred on the Coeur d'Alene River and the second largest on the St. Maries River and the Palouse River. Landslides associated with the 1974 events were documented by Megahan et al. (1978).

Large water inputs to the soil surface trigger both landslides and floods. In the Pacific Northwest the largest water inputs come from rainfall, snowmelt or a combination of rainfall and snowmelt known as rain-on-snow. These associations are well known across the Pacific Northwest.

The landslide events of the winter of 1995-96 fall into three distinct episodes. The first was November and December 1995, followed by February 1996. The last episode was during the spring melt of 1996. Each of these episodes will be discussed.

November 1995 Weather Conditions

During October through November of 1995, precipitation in the Clearwater River drainage was nearly 200 percent of normal. The North Fork Clearwater drainage received 26.1 inches of precipitation compared to the normal 2-month average of 13.4 inches. The Lolo Creek drainage received 26.7 inches compared to its average of 13.4 inches. The Lochsa River

drainage received 17.3 inches of precipitation compared to an average of 8.7 inches (Personal communication, Clearwater National Forest).

The Powell Ranger Station had 26 days with measurable precipitation between November 1 and December 4. Daily precipitation amounts varied from 0.01 inches to 2.3 inches, with more than 0.5 inches on 13 days. Snow depth at 3,400 feet peaked at 12 inches on November 11. November 23 was the first of 13 consecutive days of precipitation (Pipp et al., 1997).

Stream flows integrate the snowmelt and rainfall events. The North Fork Clearwater at the Canyon Ranger Station peaked at 37,400 cubic feet per second (cfs). This flow was the ninth highest in 41 years of record, a 25-year event. The Clearwater at Orofino peaked at 79,700 cfs, the third highest flow in 38 years of record, a 25-yr event. The Lochsa River near Lowell recorded a flow of 28,000 cfs, the sixth largest flow in 67 years, a 10-year event. A flow of 14,600 cfs on the Palouse River at Potlatch was the highest flow in 35 years. The Selway near Lowell experienced a flow of 28,400 cfs, the 22nd largest in 66 years, a 2-year event. It is clear that within the bulk of the Clearwater NF the November event resulted in substantial streamflows.

February 1996 Weather Conditions

The events leading to the February landslides were similar to those during November, i.e., warm temperatures and several days of rainfall on a deep, widespread snowpack. By February 4, snow depths at Orofino, Idaho, were 19 inches, with 36 inches in the surrounding hills. Beginning on February 7, a powerful storm swept into the inland Pacific Northwest from the Pacific Ocean bringing strong, warm winds and several inches of rainfall to the above-average snowpack. Ice jams on some rivers added to flood problems. The resulting floods, the worst since 1974, forced evacuation of many low-lying areas and extensively damaged public and private property (U.S. Department of the Interior, 1996). Fifteen northern Idaho counties, including Clearwater and Latah Counties, were declared Flood Disaster Areas.

Streams received both snowmelt and rainfall runoff. High flows were not as severe in the two drainages at higher elevations (Lochsa and Selway) as in the drainages at lower elevations (Clearwater and North Fork Clearwater). The Selway reached a flow of 16,600 cfs, the 58th highest flow in 66 years. The Lochsa River reached a flow of 14,600 cfs, the 50th highest flow in 67 years. The North Fork Clearwater peaked at 30,800 cfs, the 18th highest flow in 41 years. The Clearwater at Orofino peaked at 62,900 cfs, the ninth highest flow in 38 years. Stream flows adjacent to the Clearwater River basin were large. The Coeur d'Alene River experienced a 50-year event. Lolo Creek experienced a 100-year event; Lapwai Creek had a 50-year event. The Palouse River flow peaked at a 100+ year event.

As other evidence suggesting that this was a low elevation storm, streamflow and precipitation collected at Mica Creek near St. Maries, ID showed that the rain-freeze temperature was near 4,000 ft. As a result streamflows measured at 4,000 ft were 2-year events. Streamflows at

3,300 feet were 25-year events. As in the November, the February event was a substantial one causing major flooding on small streams below 4,000 ft.

Spring 1996 Weather Conditions

Anecdotal evidence from Potlatch Corp. field personnel indicated that significant landsliding occurred during the spring snowmelt season. This landsliding episode was set up by the wet antecedent conditions of the fall and winter. Peak streamflows were not unusual.

Relative Landslide Hazard

The analysis of the landslide inventory to determine relative landslide hazard will be discussed as a series of questions and answers. The questions were developed from public meetings on May 16, 1996 and November 1, 1997.

How many landslides occurred in the study area as a result of the November 1995, February 1996, and the spring 1996 events?

The number of landslides on the Clearwater NF with volume greater than 25 cubic yards was 907. The locations of the landslides visited by the field crew are shown in Figure 3. Landslides identified by aerial photo analysis are shown in Figure 4. The authors were not able to distinguish which weather event initiated individual landslides. The Clearwater NF landslide survey included the entire forest except for the wilderness area and the Palouse District.

What were the land use conditions for these slides?

Over half (58%) of the landslides were associated with roads. A road associated landslide was defined as originating between the top of the cutslope to 100 feet below the base of the fill.

Fillslope failures were by far the dominant landslide failure mode for roads, both in numbers of landslides and volume of material. Slope stability theory identifies the primary underlying cause of these failures as saturation of the fill material by subsurface water and inadequate control of surface water. A common initial condition leading to failure of fills was settlement and incipient rotational movement due to inadequate fill compaction, incorporation of organic materials in the fill, or failure to remove weak material in fill foundations. The settled fills concentrated the uncontrolled surface water into the fill, resulted in saturation, slumping, and erosion of fill material.

The high percentage of road landslides found in this study is consistent with work done on the 1964 and 1974 events throughout the Pacific Northwest. Other studies (USDA, 1997; Cundy, 1997) of the November-February 1995-96 events in the Pacific Northwest also consistently identify a high percentage of road failures.

The second highest land use was natural (no management) with 29% of the slides.

The remaining 12% of the landslides were in harvest units. This includes landslides from 40 to 50 year old stands of regenerated timber which are generally believed to have fully recovered root strength (for example, Sidle, 1985).

Landslides associated with fire totaled 2 and comprised less than 1% of the 907 landslides. The fact that only two landslides occurred in areas burned by wildfires in the past ten years surprised the authors. The two inventoried failures occurred on south facing Breaklands on the Hidden Fix burn on the North Fork District. It should be noted that wildfires occurring on the Clearwater NF over the last ten years were largely above 5,000 feet elevation or in landforms that have low landslide hazards.

There were 6 landslides (1%) that were not classified as to land use.

Quartz Creek Landslide

The Quartz Creek landslide received considerable attention in the public discussion of landsliding on the Clearwater National Forest. Therefore, the authors provide in this section an analysis of the slide itself and also discuss how its inclusion in this data set affects later portions of this report.

The first question the authors debated was whether or not to include this slide in this report. Originally the authors decided not to include this slide for the following reasons: 1) recent slide movement was noticed in May 1995; the major slide occurred in the first week of November 1995 before the main landslide episodes of November and December 1995; this led at least one expert to conclude that this was a random geologic event that was not related to hydrologic conditions near the time of the event or the land use activities in the vicinity of the event, 2) the nature of the Quartz Creek slide was much different than the other slides in this study - this slide occurred in fractured bedrock some 50 feet below the soil-bedrock interface while virtually all the other slides occurred at the soil-bedrock interface some 3 to 10 feet deep, 3) the volume of this single event was so large that it would dramatically increase sediment volumes attributed to natural events (which is how the authors categorize this slide) and detract from the necessary discussion on road-related slides and sediment.

Based on comments received during peer review and public presentation of this study's results, the authors have included the slide in the final report. The most compelling physical reason is that the slide may have been triggered by the unusually wet October and November weather that set the stage for the major landsliding episode in late November and early December.

The second question the authors debated was what land use should be associated with the slide - harvest, road, natural, or fire. Based on field reconnaissance and review of expert reports, the authors placed this slide in the natural category. While the slide started above a road, and

did cross a road, it is noted in one of the expert reports that the failure plane was well above the road prism so the road was not a factor in the slide.

It is also noted that failure was near a helicopter timber salvage unit that occurred in approximately 1987. The principal impacts of timber harvesting on landsliding are in reducing root strength and changing the water balance of the site. Root strength is not an issue in this slide because the failure plane was in bedrock and was well below the rooting zone.

With respect to the water balance of the site, the authors believe this was not a contributing factor. The harvesting would have had only a small impact on the water balance because this was a salvage sale where a substantial number of trees were already dead or dying. Second, the salvage operation took place several years ago; the maximum effects would occur immediately after harvesting and current effects would be greatly reduced. A confounding factor is that timber has continued to die on this slope since the salvage operation.

The net result of these analyses was that the authors categorized the Quartz Creek slide as natural.

The Quartz Creek slide is included in all the summaries and analyses in this report. Its impact is negligible with respect to landslide counts in various categories. Its impact is substantial in volume and delivery estimates. This single slide accounts for 73% of the volume for natural slides and 70% of the volume delivered for natural slides. The large contribution of this slide on these volume estimates should be kept in mind as the remainder of this report is reviewed and interpreted.

What were the sizes of the landslides?

Figure 5 presents the volume categories by land use. Most landslides were between 26 and 100 cubic yards regardless of land use.

How many of the landslides delivered sediment to a stream or floodplain?

Figure 6 shows the number of landslides that delivered sediment to a stream or floodplain. Except for roads the most frequent delivery category was 51 to 100%. A point to note is that the less than 10% category is the second largest. Based upon the authors' observations, a majority of the landslides in the less than 10% category did not deliver sediment to a stream or floodplain.

What is the estimated total volume of sediment? How much entered streams or floodplains?

While this question was frequently asked, the authors believe it was one of the hardest questions to answer. Two factors were responsible for the difficulty. One was the inherent problem of estimating volumes in debris avalanches and flows. These were liquid or semi-

liquid masses leaving long, narrow scars. Within the scar the event alternately scoured and deposited material. Secondly, it was difficult to determine how much of the material was subsequently removed by the high spring runoff. This was especially true for volumes estimated from aerial photo interpretation. Because of these difficulties, the authors chose to provide a range of values to answer these questions.

Volumes were estimated for 905 of the 907 landslides by the authors. For the No-see-um Creek landslide the authors used the Clearwater NF's estimate of 100,000 cubic yards. For the Quartz Creek landslide the authors used the Clearwater NF's estimate of 200,000 cubic yards. Table 1 shows the volume assigned to each volume class used in determining the total landslide volume. Table 2 shows the percent deliveries assigned to each delivery class for estimating the volume delivered to a stream or flood plain.

The authors' best estimate of the total volume displaced was 700,000 cubic yards with a range of 400,000 to 900,000 cubic yards. Thirty-six percent of the landslide volume was associated with roads, 5% with harvest, and 59% with natural.

The best estimate of the volume that delivered to streams is 400,000 cubic yards with a range of 300,000 to 700,000 cubic yards. The delivered volume from roads was 25%. Harvest landuse comprised 4% of the delivered volume. The remaining 71% was from natural landuse.

What were the geologic parent materials?

Landslides were sorted by geologic parent materials and land use. Figure 7 and Table 3 present these comparisons. Border and Batholith were the two parent materials with 84 percent of the landslides, regardless of the landuse.

What were the elevations that experienced the landslide problems?

Table 4 summarizes the elevation ranges. For rain-on-snow events such as November-December 1995 and February 1996, the elevations below about 5,000 feet were most landslide prone. There was a drop in landslide rate of greater than 0.5 landslides per 1,000 acres below 5,000 feet to near 0.1 landslides per 1,000 acres above 5,000 feet. The authors were not able to determine separate landslide rates for land usage, because the foiest was not able to provide land use by elevation.

Elevation relationships associated with landslides can also be correlated with several landscape characteristics. Ninety-four percent of all landslides occurred below 5000 feet elevation. A rather abrupt change in soil and landforming processes and resultant landforms also occurs at this elevation. Soil forming processes associated with chemical weathering below 5000 feet elevation rapidly change to processes associated with physical weathering and frost churning above 5000 feet elevation. Subalpine vegetative habitat types also start appearing near 5000

feet elevation. This suggests that these patterns are well established and long term and render portions of the landscape more susceptible to landslides than others.

What were the aspects (azimuth) of the landslides?

Table 5 shows the forest wide percentages as well as the landslide percentages and rates. The landslide rate per 1,000 acres indicated that south, southwest, and west slopes were more likely to experience landslides. This was true in all land use categories.

Hillslopes that face from south through southwest to westerly were most affected by these events. This was the general direction of the storm tracks, from coastal Oregon across the Idaho panhandle. Additionally, these directions were the ones that received the highest solar energy input leading to a warmer, wetter snowpack preceding the storm. During the storm the windward slopes received the highest latent and sensible heat transfer.

How steep were the slopes below each landslide?

Figure 8 and Table 6 present the steepnesses where landslides occurred. The steepest slopes experienced the most landslides. This is consistent with the known physics of the landsliding process.

What landforms experienced the most landslides?

Figure 9 and Table 7 present the landforms and landslide information. The figure shows that the two highest landslide rates were on Breaklands and Mass Wasting landforms.

Use of Landslide Indicators

The landslide rate indicators of parent material, landform, elevation, aspect, and hill side steepness could be used to identify landslide prone areas for planning purposes. They could be used in conjunction with site specific slope stability indicators in road location, design, construction, maintenance, and obliteration.

For large scale planning purposes the authors suggest that a GIS-based analysis of landslide hazard be undertaken. This might involve statistical procedures such as logistic regression that utilize the landslide indicators as independent variables. A thorough analysis of the more stable landforms could be completed. This analysis could identify landslide problems that were related to maintenance levels in inherently stable landforms. An analysis of landform inclusions that were collected could be used to identify and describe the inclusions that present isolated, localized areas of high landslide occurrence in otherwise stable landforms.

For site-specific evaluation, the GIS analysis may not be sufficient. Therefore, training of field personnel in landslide hazard identification is also recommended.

With correct identification of hazardous areas, appropriate road location, design, construction, maintenance and obliteration decisions can be made.

Historical Comparisons

This section compares the landslides of the winter of 1995-96 to a previous analysis by Megahan et al. (1978) which covered the period 1973-76.

During December 1973 and early January 1974, the Clearwater Mountains experienced heavy snowfalls with high water content. In mid-January, sudden warm temperatures in combination with a rain-on-snow storm accounted for 11 inches of snowmelt and approximately 3 inches of rainfall within 5 days. This episode resulted in numerous landslides. Additional slides occurred during the period of concentrated snowmelt in April and May. These two events constitute the last major landslide episode on the Clearwater NF.

The snowpack was about 10% greater than normal in the spring of 1975. No rain-on-snow events occurred during the previous winter.

In 1976, snowpack accumulation was slightly above normal. However, cool temperatures and few rainstorms reduced landslide occurrence.

The rainfall for November-December 1995 and February 1996 storm events at four stations on the Clearwater NF are listed in Table 8. The authors estimated that about 10 inches of snowmelt occurred during the February 1996 storm, implying that the total precipitation plus snowmelt were the same for both the January 1974 and February 1996 storms.

The landslide characteristics for the 1974-76 and the 1995-96 events are compared in Table 9. Megahan et al. (1978) reported that a relatively long, cool spring minimized the number and severity of landslides. The data in Table 9 shows that landslide numbers were not greatly reduced through the study period, however, the landslide volumes and delivered volumes were greatly reduced. The average landslide size was higher for the 1974 event than for the 1995-96 events. The total volume, delivered volume to streams, and the percent delivery was higher in 1995-96.

Table 10 provides comparisons of the landslide rates for the geologic parent materials between the 1974-76 and 1995-96 events. The higher rate of batholith failures for the 1995-96 events may be due to a longer period for accumulating granitic grus since the last significant storm event. For the 1974 event it had been 10 years since the most recent flood event in 1964. For the 1995-96 events it had been 21 years since the 1974 event.

Table 11 displays the landslide origins by land use for the two studies. The road and harvest proportions and natural plus fire are remarkably close for the two storm sequences. The fire related landslide occurrence was very low for the 1995-96 events because there had not been

recent large fires on the Clearwater NF in the affected area.

From Table 12 it is evident that for the 1995-96 event, cut slopes failed much less frequently than fill slopes. The authors' preferred explanation was that the 1974 study had a lower landslide volume threshold of 10 cubic yards and counted more cutslope failures which tend to be smaller than fillslope failures. A second explanation would be fewer cut slope failures may reflect the avoidance of geologic hazards in roads that have been constructed since the 1970's.

From the above comparisons it was evident that the methodologies, forest coverage, and threshold landslide volumes in the two studies were sufficiently different that only general comparisons could be made.

1. The January 1974 storm event was the significant event for the 1974-76 study. The precipitation plus snowmelt for the January 1974 and the February 1996 events were approximately equivalent.

2. The average landslide size was higher for the 1974-75 events than the 1995-96 events. The total volume, delivered volume to streams, and the percent delivery were higher in 1995-96. It is worth noting that 38% of the delivered volume came from two large landslides, Quartz Creek and No-see-um Creek.

3. The landslide response was similar for the three basic parent material types, with Border the most landslide prone. However, the Batholith and Belt materials reversed in landslide frequency between the two studies, possibly due to the longer period between events for the 1995-96 event compared to the 1974-76 study, allowing more time for granitic grus to accumulate.

4. The landslide rates for roads and harvest areas were nearly identical for the 1974-76 studies and 1995-96 studies. When natural landslides and landslides on burned areas were summed, the totals were nearly identical as well.

Background Sediment Rate

Wilson et al. (1982) reported an average annual sediment yield of 25 tons/sq mi/year for undisturbed drainages on the Clearwater National Forest. The natural sediment yields were generated by in-channel erosion of banks and beds. Wilson et al. distributed the natural sediment loading as follows: 20 percent due to erosion primarily from areas denuded by historic fire cycles and the remaining 80 percent to natural landslides. The bed and bank material was supplied principally by long-term mass movement and, to a lesser degree, by natural surface erosion from areas denuded by catastrophic wildfires.

Nick Gerhardt, Nez Perce National Forest hydrologist (personal communication), obtained an average annual sediment yield of 27 tons/sq mi/year for the Selway River drainage near its

confluence with the Lochsa River. The Selway River drainage has little timber harvest and few roads above the sampling location so that these results should approximate the natural background rate. No substantial landslide events occurred during the five year sampling period of 1988-1992. Average annual stream flow during this period was 82% of the 62 year average. Thus the sediment yield estimate is probably somewhat low for a long term rate, however, the authors did not adjust it for this analysis. Based on an area of 1.667 million acres for this study, the natural background rate would be about 50,000 cubic yards per year, with 40,000 cubic yards due to natural landslides.

$$27 \frac{tons}{mi^2 yr} \; x \; 1{,}667{,}000 ac \; x \; \frac{1 mi^2}{640 ac} \; x \; \frac{2000 lbs}{1 ton} \; x \; \frac{1 ft^3}{110 lbs} \; x \; \frac{1 yd^3}{27 ft^3} \; x \; 0.8 \approx 40{,}000 \frac{yd^3}{yr} \quad (1)$$

Table 13 displays the incremental sediment delivery above natural baseline sediment due to landslides for the 1974-76 and 1995-96 storm sequences. The total sediment delivered from the 1995-1996 events would provide approximately 10 times the natural background landslide sediment. The sediment increment due to delivered road sediment would be approximately 2.5 times the background rate.

Spatial Variation in Landsliding

The following discussion was prompted by a comment made during the public presentation of the findings of this report. The comment concerned whether the overall sediment delivery of 10 times background correctly represented the spatial variation in the landsliding episodes. Concern was expressed on the relative long term impacts on fisheries of chronic, spatially continuous sediment loading versus episodic, spatially patchy sediment loading. This topic is not well understood and is beyond the scope of this study. However, the discussion below is offered by the authors to address the spatial variation in sediment delivery as observed in this particular study.

The value of 10 times the background rate of sediment loading into the Clearwater basin system assumed the sediment was uniformly spread over the entire basin. What actually happened was that some watersheds were heavily impacted while others were largely unaffected by the landslides. Figures 3 and 4 showing all the landslide locations illustrates this point well. Along Deception Creek in the northern portion of the study area there was a concentration of landsliding. There are also concentrations in the Orogrande Creek (western edge), Smith Creek (southeast corner), Squaw Creek and Papoose Creek (eastern edge) areas. As an extreme example, Quartz Creek is also included, even though the sediment delivery was primarily from a single landslide.

The sediment delivery for selected watersheds is summarized in Table 14. In these extreme cases sediment delivered from this storm ranged from 5 to 270 times the background rate.

Sediment delivery from a random sample, 10%, of the total number of named watersheds is summarized in Table 15. In many of these cases the additional increment of sediment is only a fraction of the background rate.

Another example of interest is No-see-um Creek. In this case a landslide triggered an extremely large debris flow that scoured most of the sediment from the main channel and deposited it in, or near, its confluence with the mainstem of the Lochsa River. The volume of sediment delivered was estimated at 100,000 cubic yards. This represents a substantial local input of sediment that the Lochsa must process and it is not well described by a watershed average. Furthermore, the effect in No-see-um Creek itself is a new condition of sediment impoverishment. This stream now has too little sediment to provide quality fish habitat.

The examples above are intended to illustrate the spatial variation in sediment input that occurred from the 1995-96 landslide events. The examples show that this variation can be observed across the range of scales from the size of a channel confluence to the size of a river basin. The variation includes impacts of sediment inundation and sediment impoverishment.

Effectiveness of Current Road Construction Standards

There is a general belief that road construction methods changed in the late-70s to early 80s and these changes improved road stability. The best method to verify this would have been to compare landslides from roads having accurate information on the road construction technique, road alignment, and road design. The authors initially believed road construction age was an imperfect, but satisfactory surrogate for the attributes above. The number of miles of road constructed in each decade was determined by the authors. Records of when a road was constructed were imperfect and often conflicting; reconstruction added to the difficulty of determining road age. The authors decided that if the original road alignment was not altered by reconstruction, the appropriate age was the original construction date. Alternatively if the reconstruction changed alignment, the reconstruction age was the appropriate one. However, records at this level of detail were imperfect.

Figure 10 presents the number of landslides per mile of road by decade of road construction. The highest rate of landslides was from road constructed in the 1950's and declined thereafter. The authors compared the three decades of the 1940's, 1950's and 1960's to the three decades of the 1970's, 1980's and the 1990's using a statistical t-test. The p-value was 0.12 indicating that the authors can be 88% confident that there is a statistically significant difference between the mean landslide rate of roads constructed in the 1940's, 1950's, and 1960's and the roads constructed in the 1970's, 1980's and 1990's.

A comparison between the 1974 road landslides and the 1995-96 road landslides was also possible. Figure 11 presents the Megahan et al. (1978) results of landslides per mile of road by landform and the 1995-96 data. The authors regrouped data into the same landform definitions as the 1978 study. From this figure it appeared there was a notable reduction in

road landslide rate. However, such a comparison was made difficult due to three study differences. Although neither study looked at the wilderness, the 1978 study investigated 80% of the Forest area that the authors investigated. Therefore, one would expect that the 1978 study would have lower landslide counts. Simply increasing the 1978 study by 20% did not appear appropriate. The second difference between studies was that the 1978 study used a lower limit of 10 cubic yards compared to this report with a 25 cubic yard limit. The 10 cubic yard lower limit would be expected to result in a higher number of landslides. The 1978 study contained four landslide episodes. The 1995-96 study contained 3 major events. Because the authors could not determine an acceptable methodology to adjust the results to place them on an equal basis and because some differences would make the landslides per mile increase and some would make the landslides per mile decrease, reliance on a comparison between the two studies was not rigorously justified.

While there were indications that the mix of roads on the Clearwater NF were less landslide prone, a strong scientific conclusion could not be reach by the authors. A better approach would be to do a paired road study where the only difference between the paired segments was the method of road construction.

The authors reviewed road related landslides on a variety of different landtypes which reflected different construction practices. The majority of the road landslides viewed were initiated by failing fills in road prisms. The failed fills were primarily in draws where water was concentrated by either surface or subsurface flows.

The road construction practices observed by the authors varied from sidecast construction of roads, to roads that had been located by geotechnical personnel avoiding geomorphologic hazards. Such roads were constructed by the more costly procedures of full bench and end hauling of waste material in appropriate locations. The authors reviewed six miles of roads constructed in problematic landtypes where the necessary skills, including geotechnical investigation were applied to the location, design, and construction. The authors did not find any road related landslides where adequate geotechnical input had been used. Geotechnical skills were applied to

1) avoid geomorphologic hazards in the road location;
2) adequately investigate potential hazards; and
3) dictate appropriate design and construction practices to minimize landslides.

Effectiveness of Road Obliteration

Deciding whether to maintain or to decommission a road is a matter of balancing the maintenance interval, projected use, and the stability hazard. Decommissioning is physically closing the road to travel for a period of time. The appropriate prescription should be determined for each site based upon history and hazard potential. The longer the maintenance interval, the more conservative the prescription should be. For an open road an appropriate

maintenance interval might be one to three times per year. A road closed with a gate might require maintenance every other year. For any road permanently closed to vehicle use, culverts should be removed and other provisions made to ensure control of surface water. The maintenance interval in this case may be many years. However, routine periodic, 5 to 10 year, inspections should be made to assess road prism stability. On the portions of the road network to remain open to traffic, the potential for landslides could be reduced by identifying the hazardous locations and implementing appropriate reconstruction.

The authors reviewed in the field six miles of obliterated roads. The treatments ranged from closing the road to traffic to full recontouring (pulling the fillslopes onto the road surface to restore the slope to the original contours). At the time of the 1995-96 events, the obliteration program had successfully treated 37 miles of historically unstable roads. Using road related landslides in similar parent materials, the authors would have expected up to 10 landslides from these roads. The authors were not aware of any road associated landslides occurring on the treated roads. Slides did occur on adjacent untreated roads in the same areas. Based on these observations the road obliteration program has reduced road related landslides.

Options to Reduce Landslides

The following recommendations are based upon the observations of the 1995-96 inventory of the landslide events, the authors field reviews, and their collective experiences.

Existing Roads

A systematic inventory of the existing road network and all new roads should be completed. This inventory would provide records of activities on the roads to provide needed information for road management and evaluation of the practices that are effective to reduce landslides associated with roads. The data should include information on all construction, reconstruction, maintenance, decommissioning, and major use activities on the roads. The information should include the nature, extent, and practices of each activity and how the work was accomplished. It would allow location, definition, and priorization of problem areas on a system-wide basis for treatment of the system on the most environmentally significant and hazardous situations.

The Forest has the Land System Inventory that uses stability interpretations based upon the 1974-76 landslide study as a guide to identify the hazards in each of the Forest's landtypes. Results of the 1995-96 inventory data showed only minor differences with the 1978 report. So the Forest Land System Inventory and the five landslide indicators could be used to establish the priority areas for roads to be treated through decommissioning, maintaining, or reconstruction.

Existing roads can be treated to reduce landslides in all landtypes. The existing road network has locations where the above criteria for construction were not applied. The surface water is being delivered to fills and other critical areas. Fills have subsided and invariably developed

cracks allowing water to enter the material. Many of these roads do not receive routine maintenance or even annual inspections which would allow detection and correction of these situations.

New Roads

Landslides rates on new roads can be reduced by applying known practices. The Forest Land System Inventory and the five landslide indicators could be used to identify high hazard areas. Once the high hazard areas are identified the following practices could be applied.

1) avoid the high hazardous areas where possible,
2) avoid fills on hill side steepnesses over 55%, full bench and end haul are desireable,
3) in areas of high potential of ground water, invest in a geotechnical investigation to allow an adequate and low risk design of the road prism,
4) design the road to control surface flows to avoid discharging accumulations of water on fills or any other area that has a potential to fail with the additional water. The design should include backup drainage design features. In the event that the culverts, ditches, or other drainage features were to fail to handle the water, these backup features would direct the overflow to areas of least impact rather than on large fills or other critical areas, and
5) construction of critical fills should include adequate compaction to improve the fill stability and to resist erosion.

Harvest Areas

Although landslide rates from harvest units were not large in the 1995-96 study, others (for example, Sidel et al., 1985) have found it significant. Their important factor was root strength. The Forest Land System Inventory and the five landslide indicators can be used to identify high hazardous areas. Harvest treatments that maintain root strength could be used to reduce landside hazards where the high hazard areas can not be avoided.

Options for Further Studies

Landslides occurring in harvest units was 12% of the total number and 4% of the total volume delivered. This represents a notable departure from existing Clearwater NF direction on the landslide rates in harvest units. Rational for the Forest Plan direction has been based on the 12 to 24 inch Mazama ash cap that was deposited about 6700 years ago. Using a 200-year wildfire interval these lands have been subjected to over 30 stand removal fires since the ash cap was deposited. It was concluded that the slopes that still possess an intact ash cap were not subject to landslides resulting from vegetation removal. However, photo interpretation of landslides occurring in 1995-96 found a large number of landslides in harvest units occurred on slopes that normally have ash cap soils. Because of access difficulties only a limited number of these failures were characterized on the ground. A larger portion of these landslides could be characterized on the ground to develop better onsite criteria for developing vegetation removal

guidelines. A more complete analysis of timber stand Photo Interpretation-types would better define the role of plant succession and age of harvest in defining landslide rates in harvest units and burning of various slopes.

Both the field and aerial photo inventories collected landform and slope data such as slope shape and hillslope position. An analysis of this data could be performed to aid in the development of guidelines for design and placement of harvest units.

The distance for each landslide from a stream could be analyzed to assist in road obliteration prioritize. A cursory review of road related landslides showed a higher frequency of landslides per mile from roads on slopes above streams than from roads located adjacent to streams. Findings from a detailed analysis could be used to weigh the impacts from surface erosion sedimentation against landslide sedimentation when considering road obliteration.

SUMMARY AND CONCLUSIONS

1. Of the 907 landslides on the Clearwater NF in this study, 58% were road-related, 29% were natural and 12% were associated with timber harvest. The total landslide volume was estimated to be 700,000 cubic yards with 400,000 cubic yards delivered to streams.

2. Five landslide indicators were identified in this study which can be used to locate high hazard areas. These factors were geologic parent material, elevation, aspect, hill side steepness and landform.

3. The findings of this study were similar to those of the 1974-76 study on the Clearwater NF. The total landslide volumes in the 1974-76 events were approximately three to five times the natural landslide background sediment rate. The 1995-96 events put 10 times the natural landslide background rate into the system.

4. The relation between road age and landslides was inconclusive. A rigorous statistical test yielded a p-value of 0.12. Other comparisons were confounded by differences between studies.

5. The Clearwater NF road obliteration program appears to be effective. On the obliterated roads the authors visited there were no road related landslides.

6. Use of landslide indicators can help identify high hazard areas. For new roads they can be used to avoid high hazard areas or to develop site specific road design specifications. For existing roads the indicators can help prioritize and design appropriate management ranging from open year around use to recontouring. For planned harvest units the indicators can be used to avoid unstable areas or design the harvest activities to minimize landslide hazard.

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APPENDIX A - LANDSLIDE ASSESSMENT QUESTIONS AND OBJECTIVES

The following broad objectives and questions were contained in a letter, dated April 4, 1996, from the Regional Forester, Northern Region, who initiated this study:

A. To have a dialog with the public on the causes, effects and risks of landslides to the Northern Rockies ecosystem.
B. To determine if the impacts or consequences to the ecosystem were within the natural range of variability.
C. To seek technical information useful in mitigating landslide impacts.

Some of the specific questions contained in the letter to be addressed:

1. Were the effects of the flooding within the natural range of variability for the ecosystem?
2. How significant are landslides as a source of episodic sediment delivery to streams?
3. What variables are needed to characterize the landslides?
4. How reliable are the current landform guidelines?
5. Are the characteristics of these landslides similar to those inventoried in the 1974 landslide assessment by Walt Megahan, et.al.?
6. Are the landslide mitigation measures suggested in the 1974 report still valid, and are additional measures needed?
7. How does the number and volume of landslides attributable to roads and timber harvest compare with natural landslides?
8. Are there road design elements that could be taken to mitigate landslide volume attributable to roads?
9. Was there a correlation between landslide volume generated and road age?
10. What was the affect of the road on sediment delivery to streams?
11. Was there often a significant interaction between the stream channel and the road prism?
12. To what extent did timber harvest influence sediment delivery to streams?
13. How effective have road obliteration efforts been in reducing sediment delivery to streams?
14. Have changes in road design and location been effective in reducing landslide-generated sediment to streams?

From a public meeting in Orofino on May 16, 1996, and written public comments, the following paraphrased categorical public questions were developed:

1. What was the relative size and impacts of the November-December 1995 and February 1996 storm events in comparison with previous landsliding events?
2. What were the number and relative size of landslides attributable to roads, timber harvest, and natural landscapes?
3. What were the number and relative size of landslides attributable to specific landforms?
4. Are current road water-control design criteria adequate? Are the culverts, crossdrains, ditches, surfacings, and road-surface templates sized and located to adequately control and disperse surface water?

APPENDIX B - LANDSLIDE ASSESSMENT FIELD AND AERIAL METHODOLOGY

Aerial reconnaissance flights by Clearwater National Personnel following the November and February storms determined that large number of landslides had occurred in widely dispersed inaccessible areas. Therefore it was decided that in order to get complete inventory coverage it would be necessary to supplement a field inventory with an aerial photograph based inventory. The entire forest with the exception of the Palouse district and the Selway Bitterroot Wilderness was flown in July 1996 at a scale of 1:15840 (4 inches = 1 mile).

Where possible data collected in aerial photo interpretation phase of the inventory followed the same format and used the same definitions described for the field based inventory.

The following text describes the methods and procedures used to complete Photo Interpretation Mass Wasting Data Form. The entire photo interpretation phase of the project was completed by Dale Wilson between mid October 1996 and mid February 1997.

The numbering sequence used to identify landslides inventoried using aerial photo interpretation were coded by starting with forest district code followed by 500 (Example, the first land slide inventoried on the Pierce District in the photo interpretation portion of the inventory would be 1500- 1501- 1502 ....)

Landslide 1500 is the first landslide encountered on the western most line of photos on the district starting with the southern most photo in that line. There are exceptions to this procedure involving the first 50 or so landslides inventoried on the Lochsa District.

5. Landslide locations

- Locations are marked on aerial photographs using a red horseshoe mark around the landslide origin and the outrun. The landslide number is also in red at each location on the aerial photograph.

- Landslide origins were then located on 1:2400 topographic maps using a lead pencil X and an arrow showing the outrun path. The X and arrow are circled using an orange grease pencil. Township, range, and section was taken form the topographic map at the landslides origin.

- Photo numbers were taken from the upper right corner of the aerial photo. Line number is listed below the photo number, usually in parentheses.

- Watershed name was taken from the 1:2400 topographic maps. An unnamed tributary was given the name of the next larger stream named on the map. Landslides in small unnamed tributaries draining directly into large streams, such as the Lochsa River were given the Lochsa River name.

2. Landslide Source Description

- Landslides occurring below road fills but within 100 feet of a road were classified as road related. It was assumed that drainage form the road was primary cause of failure.

- Fire was named as a source only if the area had been burned by a wildfire in the proceeding 10 years.

- Presence of old landslides is difficult to determine during photo interpretation. The landslide had to br pretty obvious to the classifier had to have personal knowledge of previous landslides before a yes classification was given to the landslide.

3 Topographic and Geomorphic Data

- Open slope, Dissection, and Open Slope into Dissections were classifications used to describe what position in slope the landslide originated. Open slope classification was given to a landslide that did not occur in or immediately adjacent to a slope dissections. A Dissection classification was given to landslides that occurred either in or at the head of a discernable "V" shaped slope dissection.

- Slope shape was placed in one of nine classes defined by (ASCE in ? Quote). Only those portions of slopes adjacent to the slide origin were used in the slope shape classification,

- Aspect was recorded using the four divisions of each quadrant (i.e. NNE, NE ENE, E).

- A landslide associated with a swale was commonly used in conjunction with the "open slope classification." The major slope break classification was used to denote land form changes that could be associated with slope gradient changes of more than 15%.

- Slope distances above and below landslide origins were measured on topographic maps. Distances were measured to a major slope break or to a major dissection . Major dissections were usually second order or higher and contained intermittent or perennial streams.

- Slope gradients below 60% were estimated using stereo pairs using 5% intervals. All slope gradients above 60% were given 60+% classification.

Type of Landside

Translational classification was given to natural landslides originating on steep slopes with soils less than 48" deep over hard bedrock and road fill failures that occurred directly on hard bedrock..

A "rotational" classification was given to landslides that had a failure surface in the soil mantle and not directly on hard bedrock. Soil mantle saturation is associated with the "rotational" landslide; consequently many turn in "decline avalanches". Landslides starting in intermittent and perennial channels were classified as "debris flows." The "debris flows" classification was also given to outruns resulting from debris avalanches entering intermittent or perennial channels.

- Elevation at the top of the failures was taken from 1:24000 topographic maps.

- Distance to intermittent or perennial streams is self explanatory.

- Landtype class (official) uses landtype scanned into GIS from landtype maps from the Clearwater Land System Inventory.

- Landtype phase is a classification to the area immediately surrounding the slide origin. This is a site classification and is one component of the mapped landtype. The form should read landtype phase at origin instead of inclusion at origin. Landtype phases bed to be written up as a separate document and is detailed in the future needs portion of the main report.

- Geology of the landslide site - uses the same parent material grouping used in the Clearwater Land System Inventory and are detailed in the main report.

4. Road Failures (Road Related Landslides)

   Road prism failure was used when the entire road from the top of the cut to the bottom of the fill failed. Road Cut and fill failure was used when only that portion of the road failed. Both cut and fill failure classes were used if both cut and fill, but not the entire prism failed..

5. Harvest Unit Failures

- Location of failures refer to that portion of a cutting unit that failed. The dissection and open slope classes used the same criteria used for those classes under the Topographic and Geomorphic Data heading.

- Logging method was assigned using aerial photo interpretation and personal knowledge of the interpreter.

6. Landslide Size

- Total length including debris flow refers to the distance of movement form the landslide origin to point where the movement of the landslide including the outrun is no longer identifiable on aerial photographs. The user should note that if a debris flow is recorded, the total length recorded will be greater than that recorded for distance to live water (intermittent or perennial stream)

- Volume class estimate determinations for both field measurement and aerial photo interpretation are subject to large inconsistent measurement errors and is discussed in more detail in other portions of this report.

Volume classes used are:

<25 cu. yd.
25-100 cu. yd.
101-200 cu. yd.
201-1000 cu. yd.
1000+

The <25 cu. yd class was used only on landslides that turned into debris avalanches and debris flows and were delivered into intermittent or perennial streams. Landslides <25 cu. yd of a small local non-delivery natural were not inventoried because of the large numbers and low impact.

Delivery classes used : <10%
11-25%
26-50%
51-100%
100%+

The 100%+ class was used with landslides that were accompanied by debris avalanches and debris flows.

7. Timber Stand P. I. Type-Standard Photo Interpretation classes used in the Clearwater National Forest stand data base were used to characterize the vegetation at the point of landslide origin. The classification procedure is defined in the Forest Service Handbook, 2409,21h, Clearwater Supplement #2 4/89, and the following was used to

describe the stand strata classification:

Code	Description
WATER	WATER
ROCK	Rock; talus
NSBARE	Apparently Nonstocked with less than 50% brush
NSSERL	Apparently Nonstocked with seral brush
NSALDR	Apparently Nonstocked with alder
SEDLING	Seedlings
HSAPL_	High stocked saplings
MSAPL_	Medium stocked saplings
LSAPL_	Low stocked saplings
HPOLE_	High stocked poletimber
MPOLE_	Medium stocked poletimber
LPOLE_	Low stocked poletimber
HSSAW_	High stocked small sawtimber
MSSAW_	Medium stocked small sawtimber
LSSAW_	Low stocked small sawtimber
HSAWT_	High stocked large sawtimber
MSAWT_	Medium stocked large sawtimber
LSAWT_	Low stocked large sawtimber
MULT_	Multiple size class

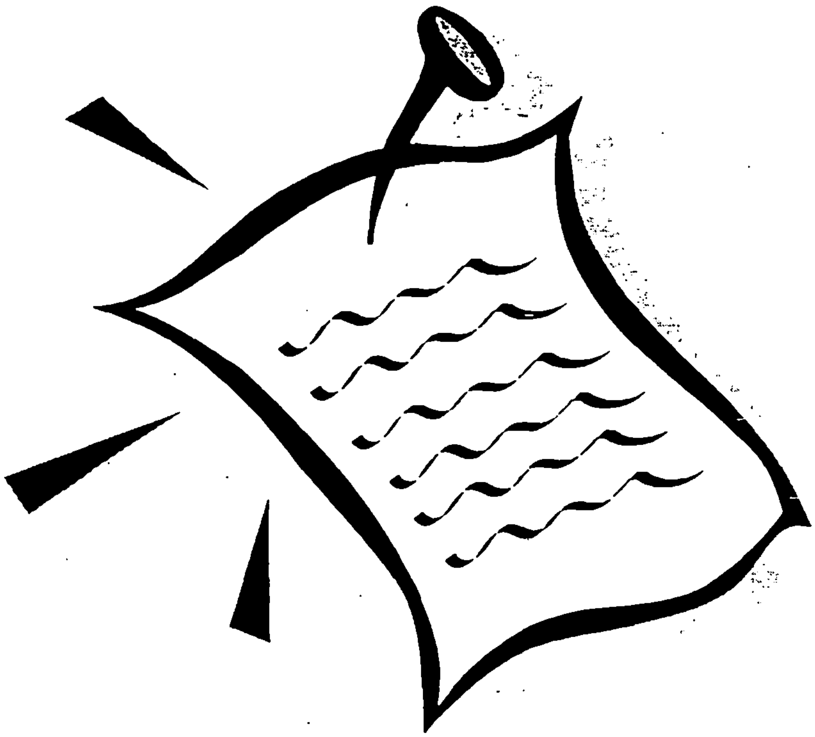
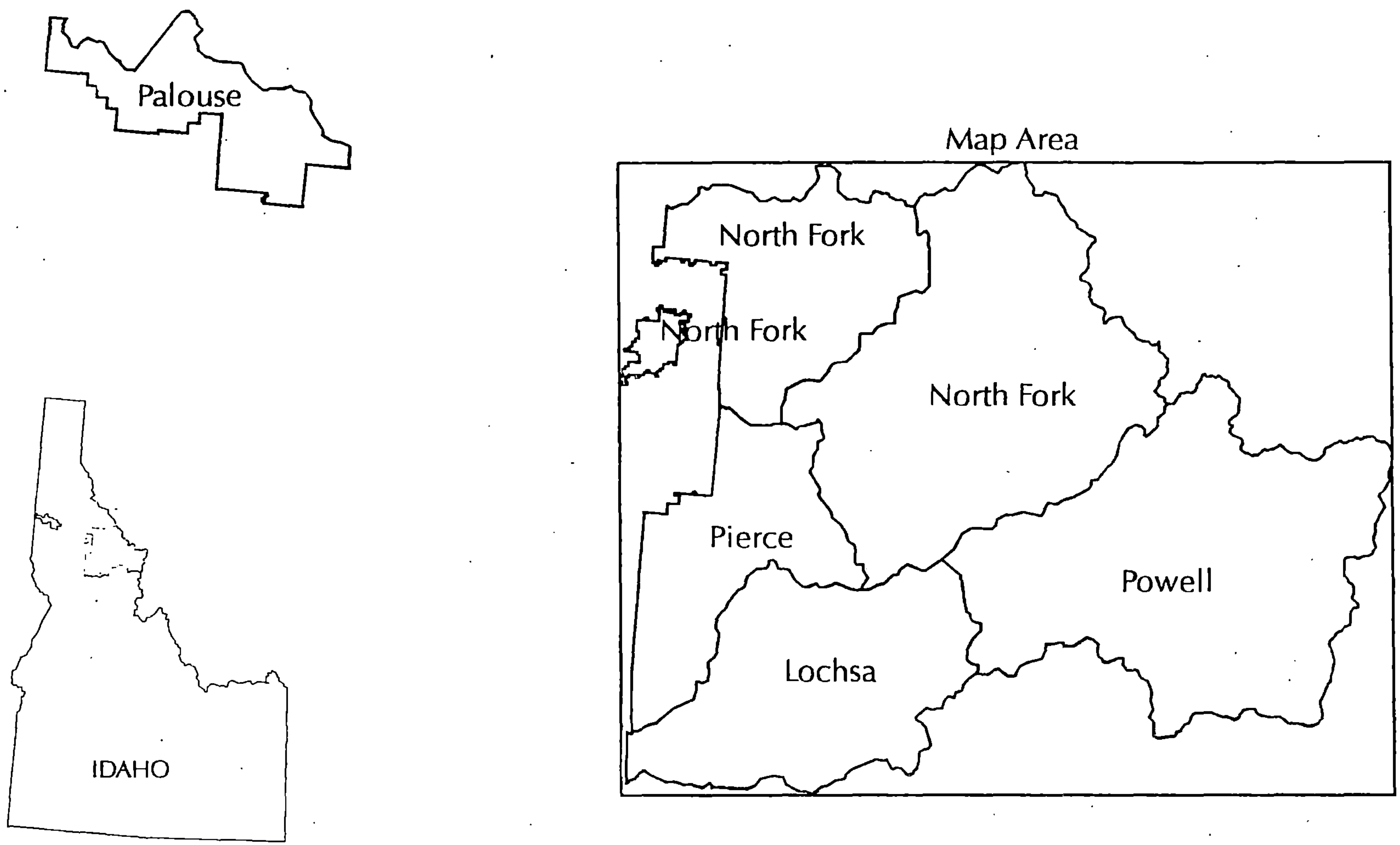


Figure 1- Location Map of the Clearwater National Forest

Ranger Districts, Clearwater National Forest, Idaho



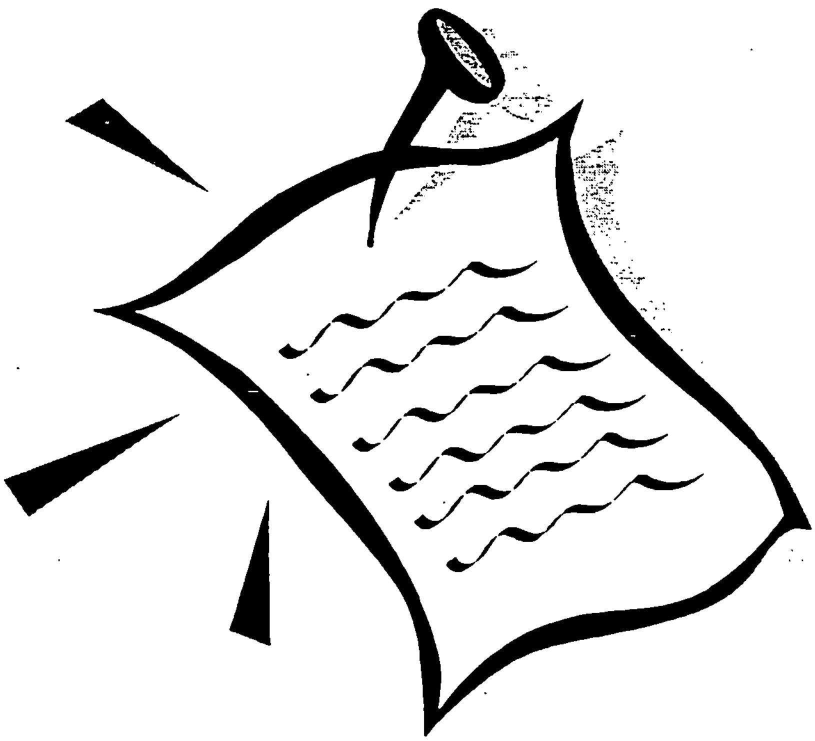
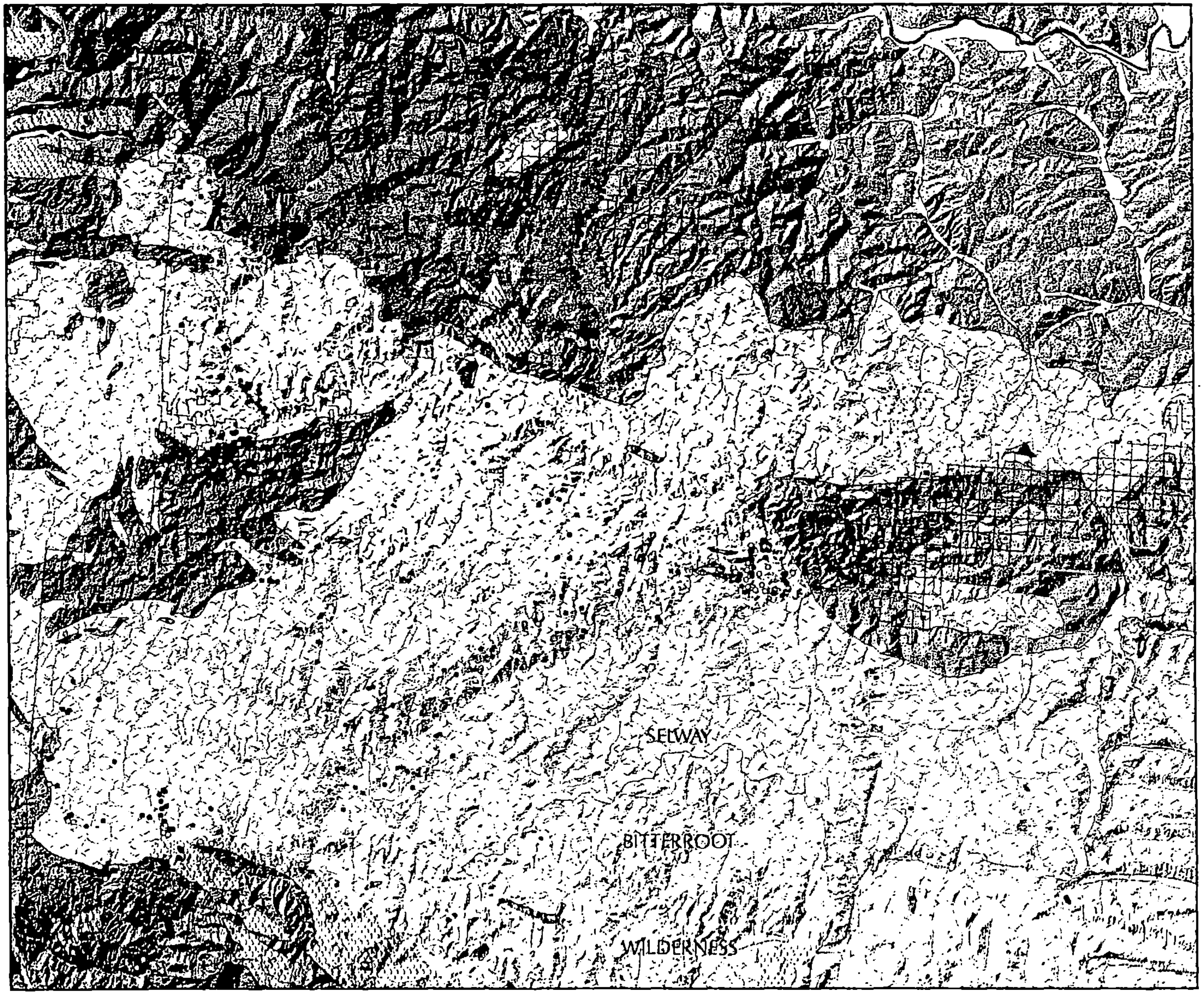


Figure 2- Generalized Geology Map of the Clearwater NF

U.S. DEPARTMENT OF AGRICULTURE
UNITED STATES FOREST SERVICE

Parent Materials

Geology Program
Digital Mapping



Rock Types

- Quaternary Sediment
- Basalt
- Belt Supergroup
- Idaho Batholith
- Border Zone

Slide Location

- Road
- Timber Harvest
- Fire
- Natural

Forest Boundary

Wilderness Boundary

ALBERS EQUAL AREA CONIC PROJECTION

0 1 2 3 4 5 Miles

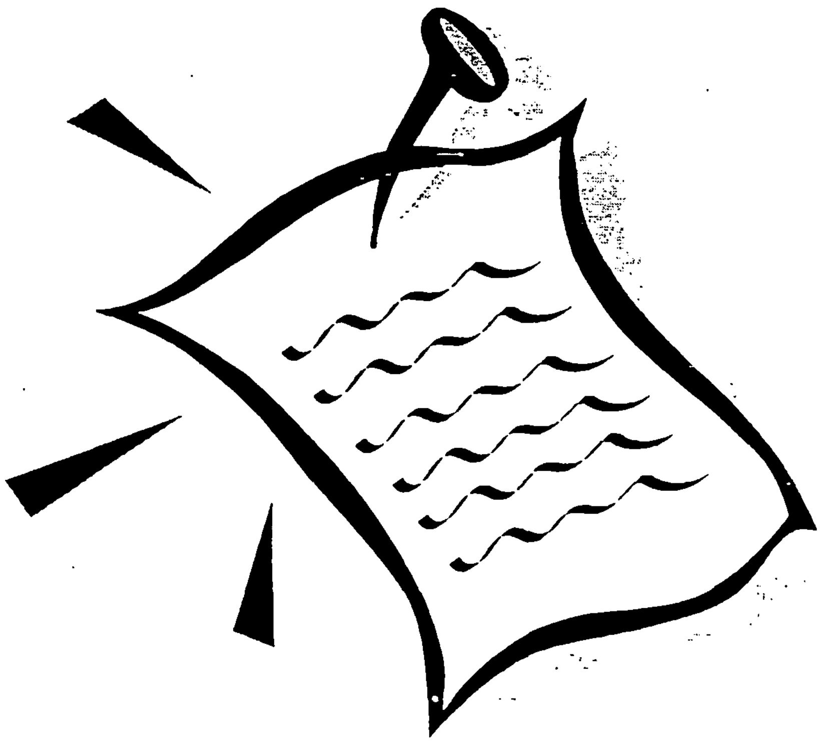
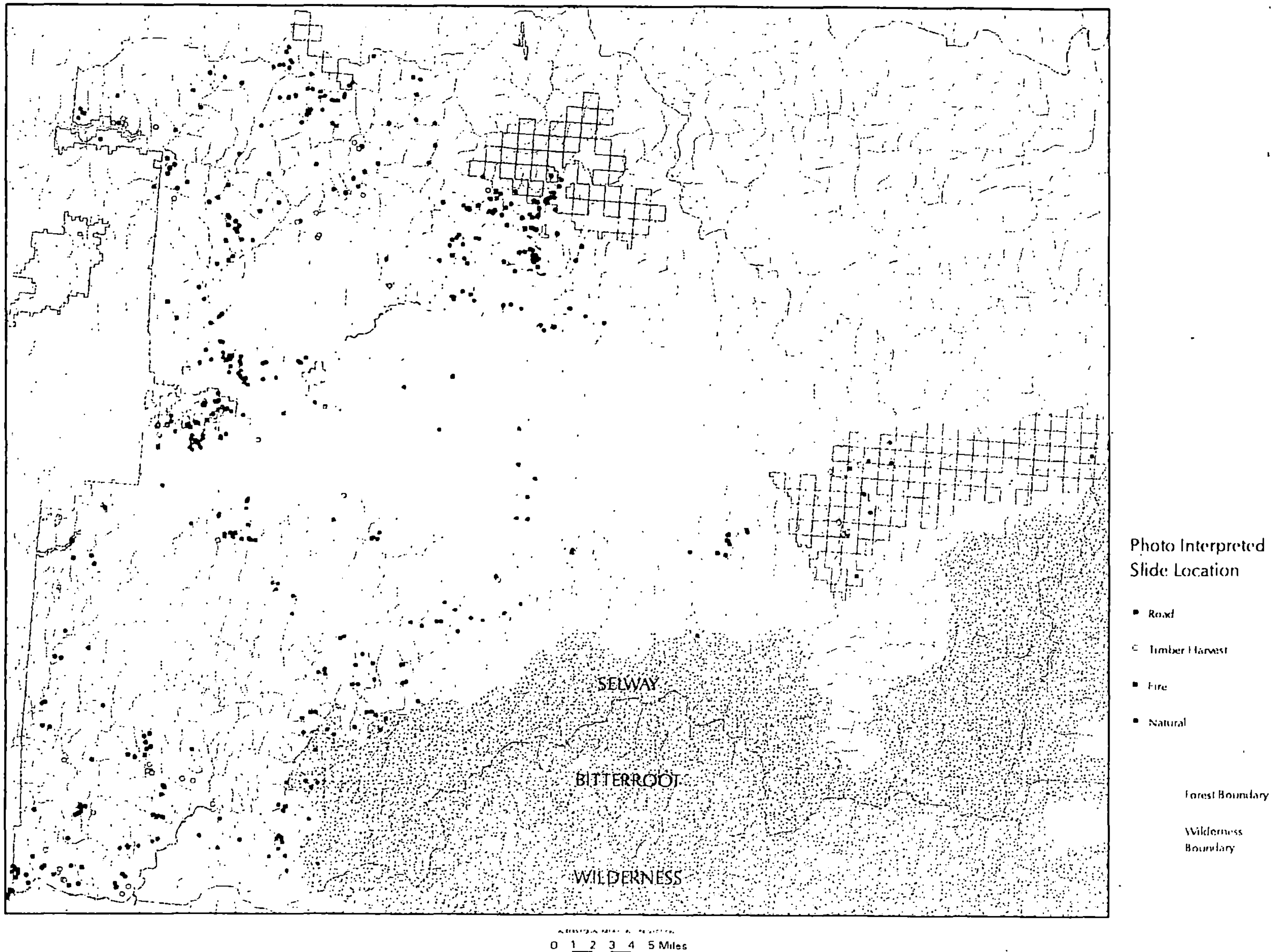


Figure 3- Map of Landslide Locations Identified by Field Crews

U.S. DEPARTMENT OF AGRICULTURE
UNITED STATES FOREST SERVICE

Geology Program
Digital Mapping

Landslide Location



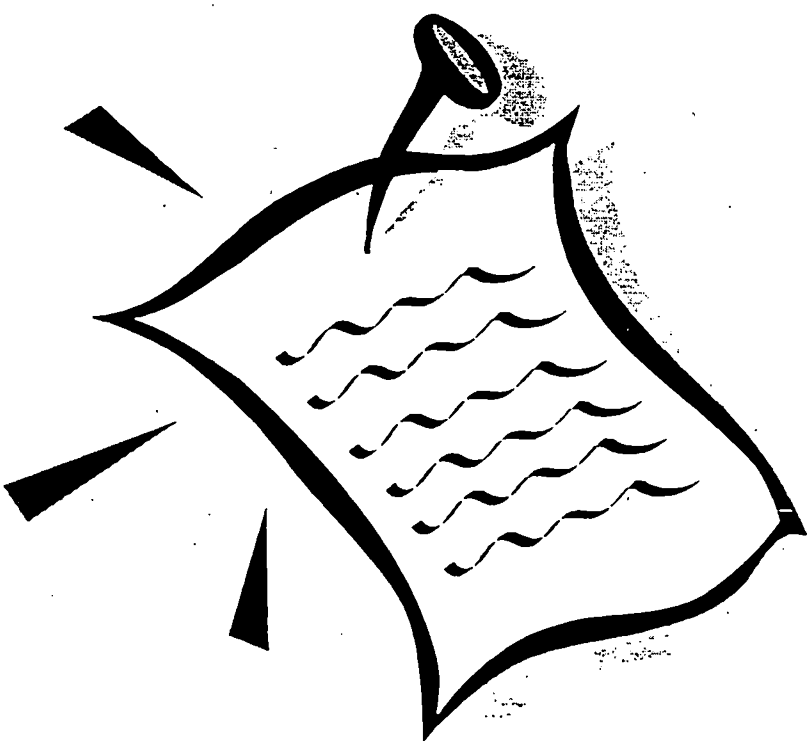


Figure 4 - Map of Landslide Locations Identified by Aerial Photo Interpretation

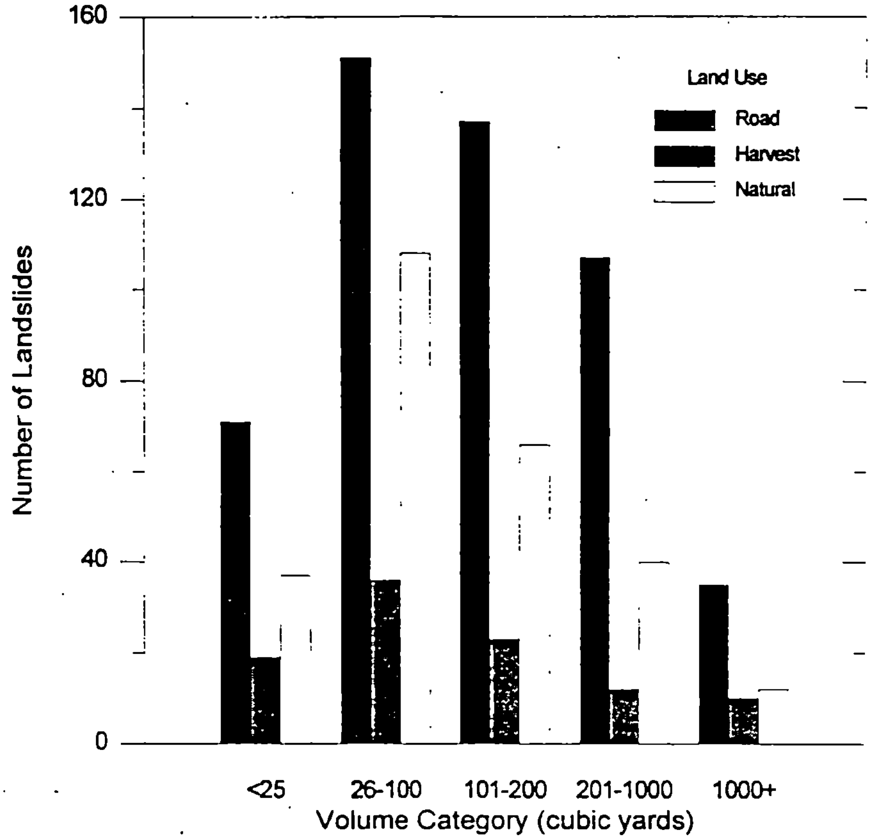
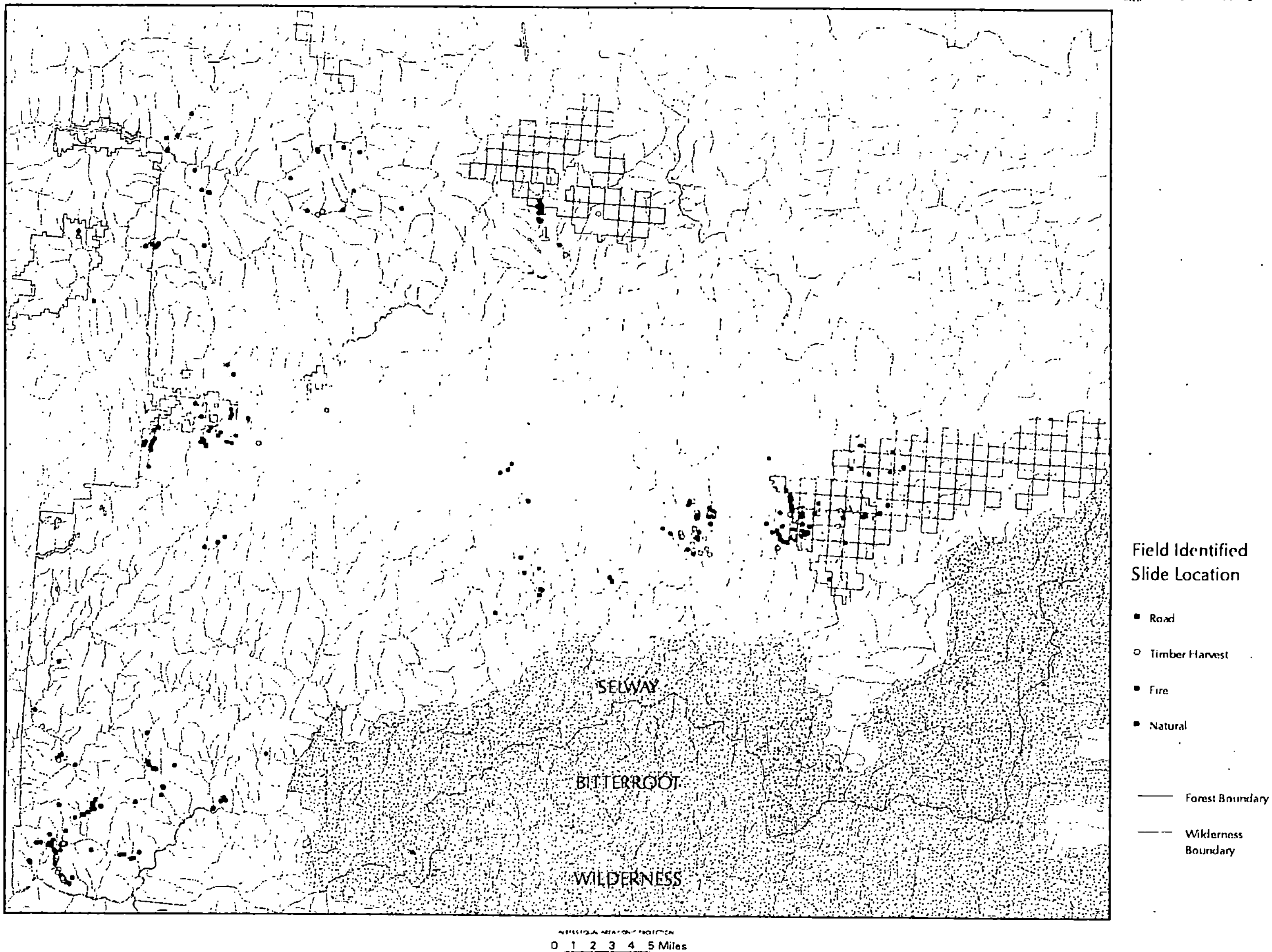


Figure 5 - Number of Landslides by Size and Land Use

U.S. DEPARTMENT OF AGRICULTURE
UNITED STATES FOREST SERVICE

Landslide Location

Geology Program
Digital Mapping



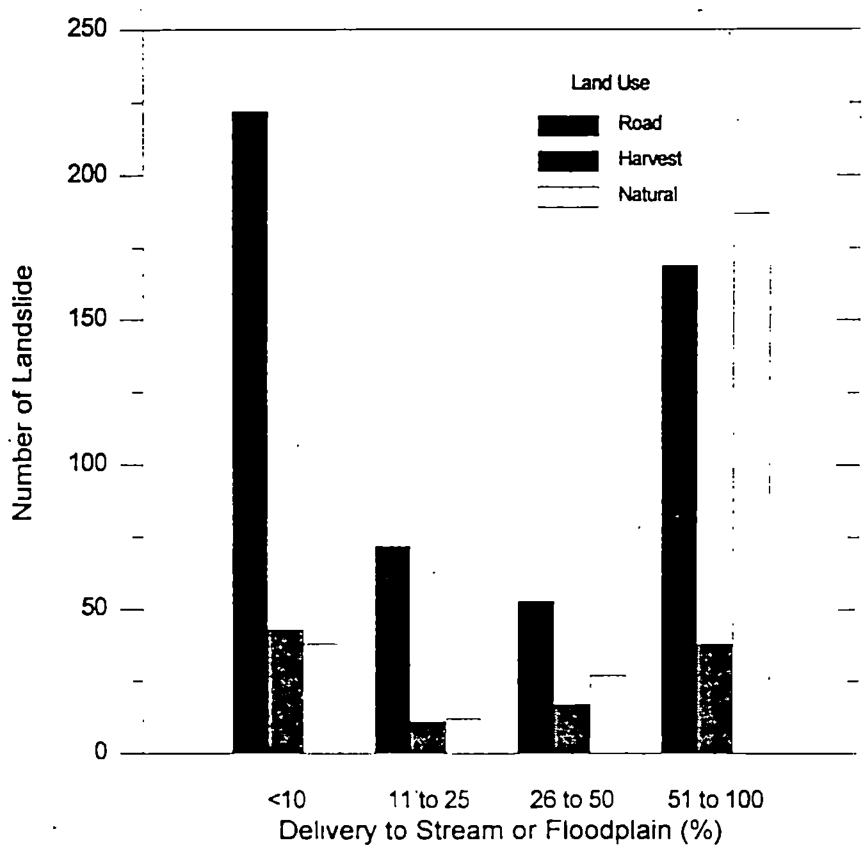


Figure 6 - Delivery of Sediment to Stream or Floodplain by Land Use

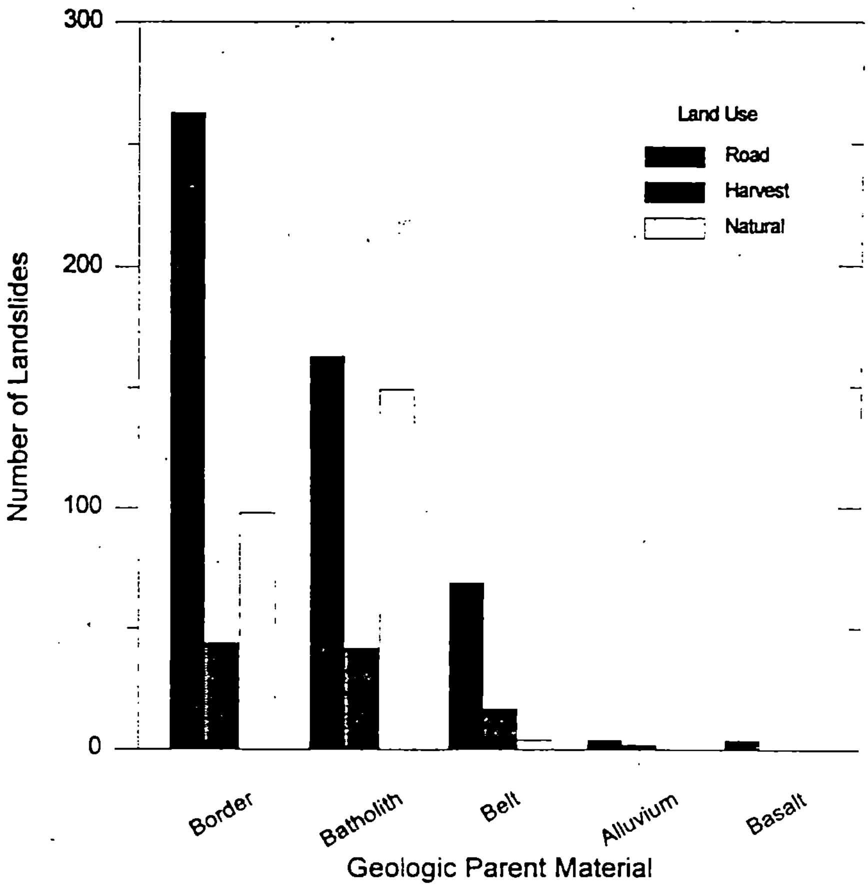


Figure 7 - Number of Landslides by Geologic Parent Material and Land Use

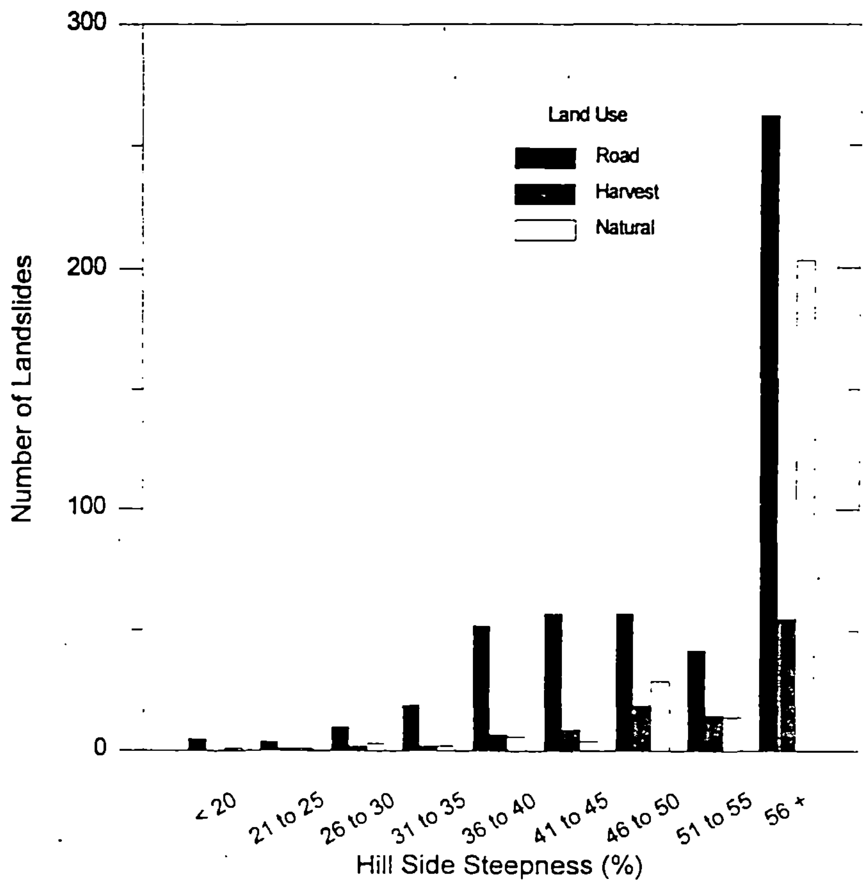


Figure 8 - Number of Landslides by Hillside Steepness and Land Use

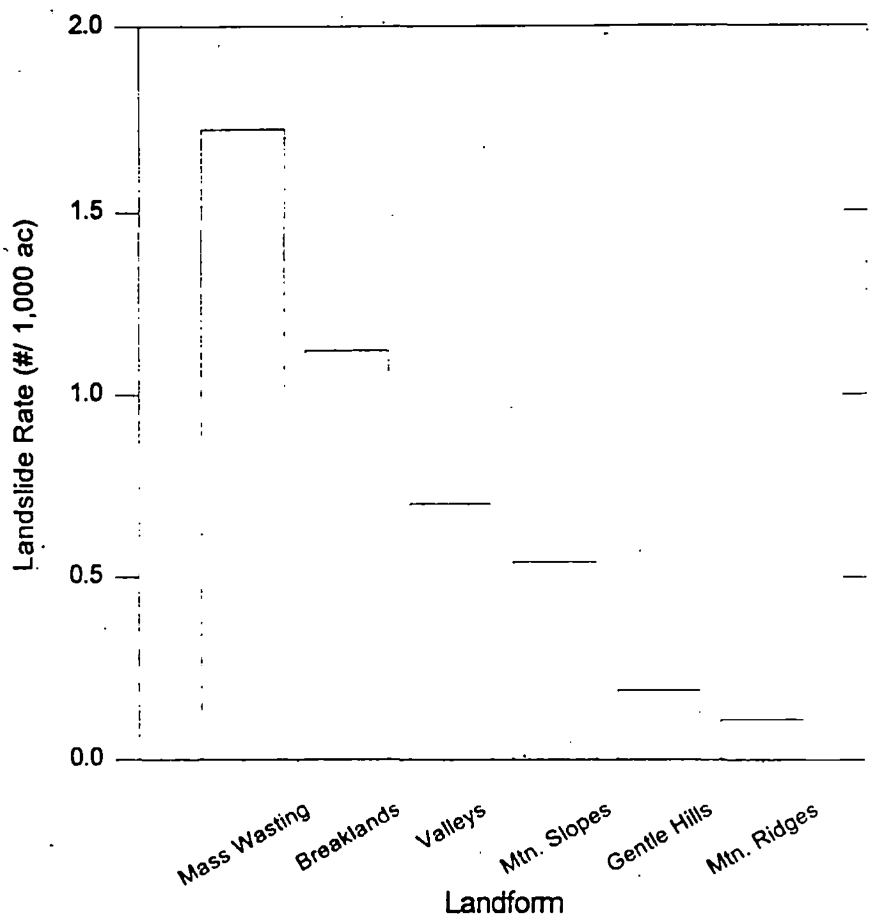


Figure 9 - Landslide Rate by Landform

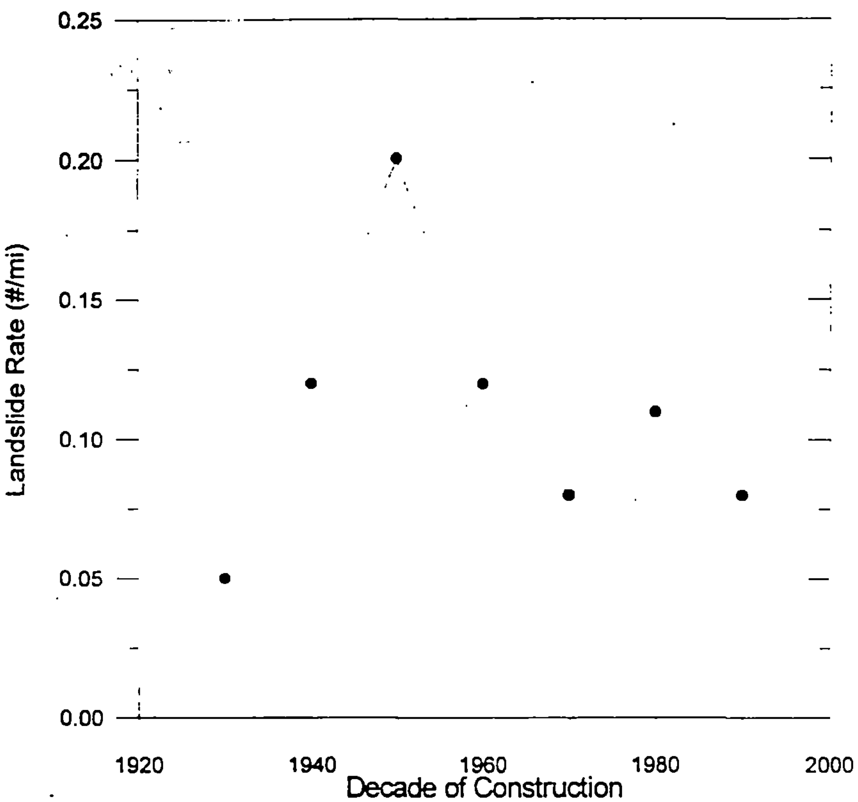


Figure 10 - Road Landslide Rate by Decade of Road Construction

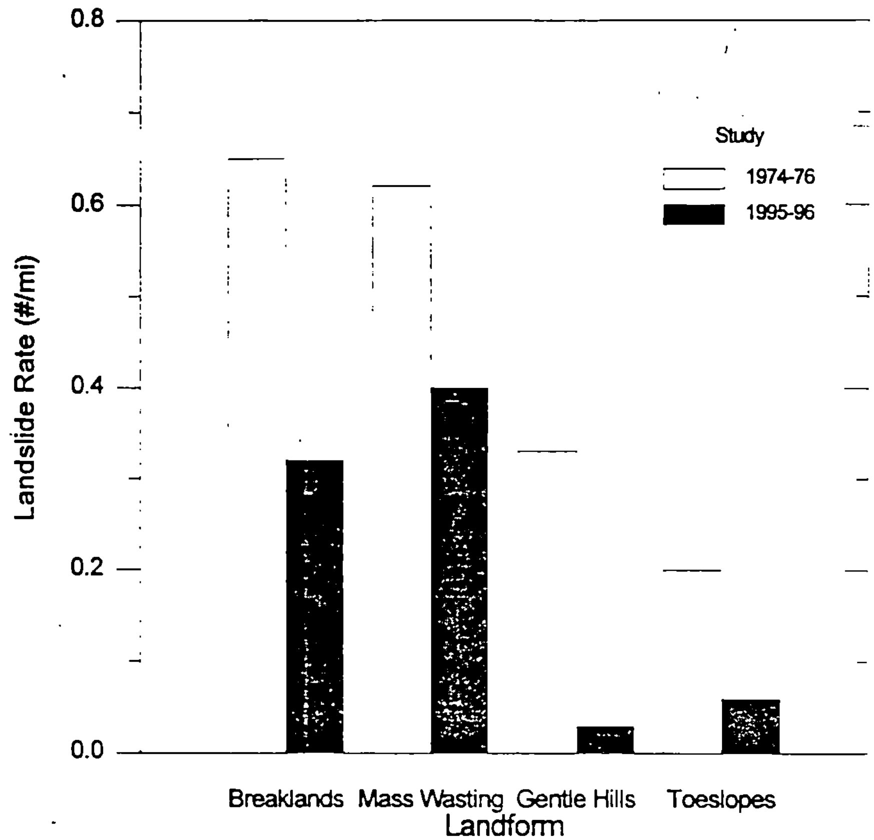


Figure 11 - Road Landslide Rate by Landform - Comparison Between 1974-76 Study and 1995-96 Study

Table 1 - Values Used in Determining Estimated Total Volume

Volume Category (yd^3)	Lower Volume Estimate (yd^3)	Best Volume Estimate (yd^3)	Upper Volume Estimate (yd^3)
less than 25	10	25	25
26 to 100	25	60	100
101 to 200	100	150	200
201 to 1000	200	600	1000
greater than 1000	1000	1500	2000

Table 2 - Values Used in Determining Volume of Sediment That Reached a Floodplain

Delivery Category (%)	Lower Delivery Estimate (%)	Best Delivery Estimate (%)	Upper Delivery Estimate (%)
less than 10	2	5	10
11 to 25	10	18	25
26 to 50	26	38	50
51 to 100	51	75	100

Table 3 - Number of Landslides by Geologic Parent Material and Land Use

Parent Material	Percent on Forest	Total Landslides		Road Landslides			Harvest Landslides	Natural Landslides
		Number	per 1,000 ac	Number	Percent on Forest	per mile		
Border	25	407	0.89	263	40	0.16	44	99
Batholith	39	358	0.51	163	43	0.09	42	150
Belt	14	90	0.36	69	12	0.14	17	4
Alluvium	8	6	0.04	4	2	0.06	2	0
Basalt	2	4	0.03	4	2	****	0	0
No data		42		19			5	14
Total	88	907		522			110	267

Note: Road, harvest, and natural landslides do not equal the total of 907 because 2 landslides were fire related, and 6 were not classified as to land use.

Table 4 - Landslide Occurence by Elevation and Land Use

Elevation Range (ft)	Percent of Forest	Number of Landslides	Landslides per 1,000 ac	Number of Road Landslides	Number of Harvest Landslides	Number of Natural Landslides
< 2000	1	20	1.65	11	5	4
2001 to 2500	2	29	0.90	14	6	9
2501 to 3000	3	81	1.48	24	5	51
3001 to 3500	6	184	1.66	115	20	47
3501 to 4000	11	203	1.10	127	19	53
4001 to 4500	14	206	0.85	139	31	35
4501 to 5000	16	137	0.50	73	21	43
5001 to 5500	16	32	0.12	13	2	17
5501 to 6000	14	5	0.02	1	0	4
6001 to 6500	17	1	0.01	0	0	2
No Data		9		5	1	3
Total	100	907		522	110	267

Note: Road, harvest, and natural landslides do not equal the total of 907 because 2 landslides were fire related, and 6 were not classified as to land use.

Table 5 - Landslide Occurrence by Aspect and Land Use

Aspect	Percent of Forest	Number of Landslides	Landslides per 1,000 ac	Number of		
				Road Landslides	Harvest Landslides	Natural Landslides
North	11	39	0.21	21	7	10
Northeast	11	40	0.21	25	11	3
East	13	78	0.36	46	1	29
Southeast	13	86	0.38	47	8	30
South	12	200	1	94	25	80
Southwest	12	187	0.89	100	21	65
West	15	187	0.74	127	26	34
Northwest	14	75	0.31	52	9	14
No Data		15		10	2	2
Total	100	907		522	110	267

Note: Road, harvest, and natural landslides do not equal the total of 907 because 2 landslides were fire related, and 6 were not classified as to land use.

Table 6 - Number of Landslides by Hillside Steepness and Land Use

Hillside Steepness (%)	Percent of Forest	Number of Landslides	Landslides per 1,000 ac	Number of		
				Road Landslides	Harvest Landslides	Natural Landslides
< 20	19	6	0.02	5	0	1
21 to 25	9	6	0.04	4	1	1
26 to 30	10	15	0.08	10	2	3
31 to 35	11	23	0.12	19	2	2
36 to 40	10	66	0.37	52	7	6
41 to 45	10	70	0.43	57	9	4
46 to 50	8	105	0.73	57	19	29
51 to 55	7	71	0.59	42	15	14
> 56	15	527	2.00	262	55	205
No Data		18		14	0	2
Total	100	907		522	110	267

Note: Road, harvest, and natural landslides do not equal the total of 907 because 2 landslides were fire related, and 6 were not classified as to land use.

Table 7 - Landslides by Landform and Land Use

Landform	Percent of Forest	Number of Landslides	Landslides per 1,000 ac	Road Landslides		Number of Harvest Landslides	Number of Natural Landslides
				Number	per mile		
Breaklands	24	507	1.12	247	0.32	51	192
Mountain Slopes	15	149	0.54	106	0.07	24	20
Mountain Ridge	18	38	0.11	23	0.03	6	11
Gentle Hills	25	87	0.19	77	0.03	4	3
Mass Wasting	2	64	1.72	42	0.40	15	7
Valley	2	26	0.70	16	0.07	6	3
Total	86	871		511		106	236

Note: Totals do not add because the landforms shown do not include all landforms on the Clearwater NF.

Table 8 - Precipitation for November-December 1995 and February 1996 Events

	Nov-Dec 1995 (5 day total) (in)	February 1996 (5 day total) (in)
Fenn Ranger Station	6.26	4.08
Headquarters	4.58	4.14
Pierce	6.07	4.49
Powell	6.32	5.34
Average	5.81	4.5

Table 9 - Landslide Characteristics - Comparison Between 1974-76 Study and 1995-96 Study

Year	Number of Landslides	Average Size (yd^3)	Total Volume (yd^3)	Delivered Volume (yd^3)	Delivery (%)
1974	214	1650	353,000	113,000	32
1975	227	1120	254,000	41,000	16
1976	188	580	109,000	12,000	11
1995-96	907	770	700,000	400,000	57

Note: The 1974-76 study covered 80% of the 1995-96 study area.

Table 10 - Landslide Parent Material - Comparison Between 1974-76 Study and 1995-96 Study

Parent Material	1974-75 (%)	1976 (%)	1995-96 (%)	1974-76 ($\#/mi^2$)	1995-96 ($\#/mi^2$)
Border	53	50	45	0.35	0.62
Batholith	21	40	39	0.15	0.35
Belt	22	10	10	0.34	0.25
Other	4	-	6	0.24	0.17
Total	100	100	100		

Table 11 - Landslides by Land Use - Comparison Between 1974-76 Study and 1995-96 Study

Land Use	1974-76 (%)	1995-96 (%)
Roads	58	57
Natural	3	29
Harvest	12	12
Fire	27	2
Total	100	100

Table 12 - Road Related Landslides - Comparison Between 1974-76 Study and 1995-96 Study

	1974-1976		1995-96	
	Road Landslide (%)	Road Volume (%)	Road Landslide (%)	Road Volume (%)
Cut Slope	66	60	17	10
Fillslope	34	40	75	90

Note: Percentages for the 1995-96 study are based on 224 landslides visited by the field crews.

Table 13 - Landslide Sediment Volume Delivered to Streams or Floodplains - Comparison Between 1974-76 Study and 1995-96 Study

Year	Delivered Volume (yd^3)	Sediment Loading (ratio to background)
1974 Total	113,000	2.8
1975 Total	41,000	1
1976 Total	12,000	0.3
1995-96 Total	400,000	10
1995-96 Roads	100,000	2.5
1995-96 Natural	287,000	7.2
1995-96 Harvest	16,000	0.4

Note: Sediment loading was based upon a natural background of 40,000 cubic yards.

Table 14 - Landslide Sediment Delivery in Selected Watersheds with High Landslide Rates

Watershed	Watershed Size (ac)	Volume Delivered (yd^3)	Sediment Loading (ratio to background)
Quartz Creek	17907	200,800	270
Squaw Creek	10823	7730	17
Papoose Creek	10430	4260	10
Pete King Creek	9184	2730	7
Smith Creek	3119	590	4.5

Table 15 - Landslide Sediment Delivery in Randomly Chosen Watersheds

Watershed	Watershed Size (ac)	Volume Delivered (yd^3)	Sediment Loading (ratio to background)
Pete Ott Creek	3674	1500	9.7
Tamarack Creek	3909	1450	8.8
Rye Patch Creek	1445	210	3.5
Walde Creek	5255	350	1.6
Fire Creek	11152	720	1.5
Windy Creek	9264	370	1.0
Glade Creek	3119	70	0.5
Cayuse Creek	7066	60	0.2
Salmon Creek	2633	20	0.2
Little Weitas Creek	19169	90	0.1
Lost Creek	3869	10	0.08
Dog Creek	1801	6	0.08
Sourdough Creek	3092	6	0.05
Yakus Creek	7873	20	0.05
Cold Springs Creek	6754	10	0.04
Johnny Creek	11685	20	0.04